*The*
*GEOGRAPHICAL JOURNAL*

*Vol XCVII No 5* R.G.S. *May 1941*

# RAILWAYS IN THE BALKAN PENINSULA

S. H. BEAVER

*Meeting of the Society, 31 March 1941*

EVEN a simple map of the Balkan Peninsula will show that the area is one of complex relief, with broad areas of highland, yet withal traversed by a number of fairly obvious routeways. It is fortunate indeed that comparatively easy transverse routes should exist between north and south, and between east and west, the latter linking western and central Europe with İstanbul, the gateway to the Orient, and the former leading to the Mediterranean at Salonika. The vital bottle-neck in which the two routes cross is the Morava valley between Beograd (Belgrade) and Niš (Nish). Westwards and northwards the Sava and Danube valleys provide alternative routeways leading from Beograd to western Europe *via* Zagreb and Milan or *via* Budapest and Vienna; towards the east the routes diverge at Niš to take advantage of the Maritsa trough leading towards İstanbul or the Vardar valley leading to Salonika. It is perhaps convenient, though it involves over-generalization, to think of these south-eastern routeways as being thrown off, as it were, by the triangular mountain mass of the Rodopi, the crystalline core around which the Peninsula has been built, and as following in a broad general way, though not by any means in detail, the zones of weakness between the old core and the fold ranges of Macedonia on the west and the Stara Planina (Balkan Mountains) in the north-east.

The Dinaric ranges, which separate the fertile and populous areas of Slavonia and Serbia from their natural outlets on the Adriatic coast, are very difficult to cross, though this has been achieved both by standard-gauge and narrow-gauge lines, from Zagreb to Sušak and Split, and from Beograd to Dubrovnik. Even more difficult, still uncrossed and hardly likely to be crossed by rail, are the ranges of central Albania, continuing southwards through Epirus to the Greek Pindus ranges. Moreover even the "longitudinal" line from Salonika to Athens suffers from the awkward way in which the earlier Hellenic fold ranges in eastern Greece are oriented in an east–west direction instead of north–south, so that several of these obstacles have to be crossed. The Stara Planina is a less formidable obstacle, narrower and with several possible

passes; it is crossed in two places by standard-gauge lines, and a third is nearing completion. West of the Danube gorges and north of the Sava river the southern end of the Hungarian Plain, which is only politically and not physically part of the Balkan Peninsula, is topographically much more favourable to railway development, and a network of almost western European density exists. Whilst means of egress from the Peninsula by rail are numerous in the north-west, across the Yugoslavian frontier between Beograd and the head of the Adriatic, into Hungary, Austria, and Italy, the north-eastern section is severed completely by the Danube, across which there is no bridge between that at Beograd (the new Pančevo bridge) and that at Cernavoda, in eastern Romania.

*The contrast with Britain*

The industrialization based upon coal, iron, and textiles, which gave Britain its early start in railway building contrasts markedly with the primitive agriculture and political backwardness which restrained the development of rail communications in the Balkan Peninsula during the last century. There was little coal or other exploited mineral wealth, and the constituent countries of the Peninsula were still only just finding their political and economic feet after centuries of Turkish feudalism; moreover the Turk was still, in the middle of the century, in possession of a large slice of territory stretching from the Adriatic to the Black and Aegean seas. The first railway in the Peninsula cut across its north-western corner just before 1850 (the Vienna–Trieste line), and the second cut across its north-eastern corner in 1860 (the Cernavoda–Constanța line), but neither of these was in the least concerned with the facilitation of communications within the Peninsula, and the main through route across the Peninsula was not completed until 1888. By far the greater part of the railway system has been constructed since 1880. By the 'sixties however the bulk of the British main-line network had been completed and the railway had established its undisputed position as carrier of the nation's goods and people.

A further point of contrast with Britain is the constantly changing political scene in the Balkans. This has entailed frequent alterations in the frontiers between the various states, which changes have had a noticeable effect on the development of the railway pattern. One line, already built, may have been rendered almost useless by the interposition of a frontier across its track, in another case an obvious routeway will have remained unutilized because a frontier has barred its natural outlet. A system which grew up to serve one set of political and economic conditions will be disrupted either by deductions from its territory or by large additions thereto. It must be remembered too that economic conditions have not necessarily provided the motives for railway building as in most parts of the world. A very large mileage has been deliberately constructed for military and strategic purposes, as for example the original Bosnian system and the Salonika–Alexandroupolis line, whilst the national aspirations of the Serbs and Bulgarians have been responsible for the inauguration of many projects, few of which have come to fruition in the manner planned. Moreover foreign influences, particularly from the German-speaking parts of central Europe, have been paramount at

certain periods, especially before the wars of 1912–18, and a very large proportion of the total railway mileage has been built with capital and materials from powers outside the Peninsula, especially from Austria, Germany, France, and Belgium. Locomotives were formerly mainly of Austrian build, rolling stock largely Belgian, French, or German, and as in many other parts of the world, the steel rails were very often British, mostly from South Wales.

A brief summary of the main historical events during the period of the evolution of the Balkan railway system is not out of place. In the 'sixties of last century a large part of the Peninsula was still occupied by the Turks. The independent state of Greece covered the southern extremities, as far north as a line joining the gulfs of Arta and Volo; the kingdom of Serbia covered the north-central portion, centring on the Morava valley, whilst the north-western corner, Croatia and Slavonia, were part of the kingdom of Hungary. The wars of 1876–78 resulted in the liberation of Bulgaria and the formation of an independent Montenegro, and were followed by the occupation of Bosnia and Hercegovina by Austria. Thessaly was added to Greece in 1881 and Eastern Rumelia to Bulgaria in 1885. The comparative stability of the next twenty-five years, during which much railway building took place in many parts of the Peninsula, was violently disturbed in 1912–13 by the Balkan Wars, the net result of which was the driving of the Turks almost out of Europe, the aggrandisement of Serbia, Greece, and Bulgaria, especially the first two of these, and the creation of a new independent state of Albania. The Great War of 1914–18 may be said to have begun in the Balkans, and there was much fighting in various parts of the Peninsula; its conclusion and the treaties which followed entailed the further enlargement of Greece, the formation out of old Serbia and part of the Austro-Hungarian lands of the new Serb-Croat-Slovene kingdom, later to be known as Yugoslavia, and the diminution in area of Bulgaria. A considerable re-orientation of the railway network became necessary as a result of these great changes in the political make-up of the Peninsula, especially in Yugoslavia, where an enormous amount of reorganization and new construction were necessary not merely to repair the ravages of the war but to mould into a co-ordinated system the lines of several formerly separate political units.

The contrast with Britain is further illustrated by the following table, which indicates the density of the railway network in relation to area and population in Great Britain and the Balkan countries:

| *Country* | *Area (square miles)* | *Population*[1] *(thousands)* | *Railway mileage*[2] | *Square miles per mile of railway* | *Population per mile of railway* | *Road mileage* |
|---|---|---|---|---|---|---|
| Albania .. .. | 10,629 | 1,003 | 0 | — | — | 1,383 |
| Bulgaria .. | 39,825 | 6,078 | 2,129 | 19 | 2,855 | 19,554 |
| Greece .. .. | 50,147 | 7,108 | 1,668 | 30 | 4,261 | 8,611 |
| Yugoslavia .. | 95,576 | 15,703 | 6,591 | 13 | 2,382 | 26,047 |
| Balkan Peninsula | 196,177 | 29,892 | 10,388 | 19 | 2,877 | 55,595 |
| Great Britain .. | 88,745 | 44,795 | 20,080 | 4 | 2,231 | 179,630 |

[1] The population figures are not strictly comparable as they relate to different years: Albania, 1930 census; Bulgaria, 1934 census; Greece, 1938 estimate; Yugoslavia, 1940 estimate; Great Britain, 1931 census. This however does not materially affect the accuracy of the figures in column 5.

[2] The mileage figures relate to 1937–38.

The fourth column of the table shows that the density per unit area in Britain is almost five times as great as in the Balkan Peninsula. The density per head of population does not show so great a contrast, for those extensive areas of the Balkans which have a very small railway mileage are also sparsely populated. The question of the mileage-area relationship however does not conclude the contrast, for it has to be remembered that almost all the Balkan railways are single track, and the amount of traffic passing over the lines is small compared with the high intensity of utilization of most of the British lines. The most intensively used piece of track in the whole Peninsula is the short electrified line, only about 6 miles in length, connecting Athens with its port of Piraeus. A few years ago this line was running trains at six or seven-minute intervals throughout most of the day, and its annual total of passengers numbered over thirty millions, a figure however which was about ten times the total number of passengers carried on the entire Hellenic State railway system, on which a dozen trains a day over the main line would represent traffic of unusual intensity.[1] Even the capital cities of Beograd and Sofiya (Sofia) have no equivalent of the intensive suburban services which characterize the great cities of Britain.

The following table compares the total annual passenger and goods traffic carried on the railways of Britain and the Balkan countries in the year 1938.[2]

| *Country* | *Number of Passengers (thousands)* | *Freight (thousand tons)* |
|---|---|---|
| Bulgaria .. .. | 11,610 | 6,243 |
| Greece [1] .. .. | 5,026 | 1,922 |
| Yugoslavia .. .. | 56,136 | 20,747 |
| Balkan Peninsula .. | 72,772 | 28,912 |
| Great Britain .. .. | 1,244,080 | 264,429 |

[1] Hellenic State Railway only, representing about one-half of the total mileage in Greece (actually 823 out of 1668); no details available for the metre-gauge lines or for the Hellenic Electric Railway, which are outside the "Union Internationale."

### *The development of the Balkan railway network*

In this historical section place-names which were current at the period referred to are used on the first mention of any place; the modern equivalents are there given in brackets and are used subsequently in the text. Elsewhere the modern name is given first and the conventional in brackets. Albanian, Yugoslavian, and Turkish names are given in the official romanized form; Bulgarian names are transliterated on the R.G.S. II System. Names such as Vienna, Athens, and Salonika, which are so well known in their anglicized form, are given in that form throughout. (See folding map.)

In an attempt to fit the Balkan railway system into its historical and geographical setting, we may conveniently divide the last hundred years into a number of fairly distinct periods.

*Slovenia and Croatia, and the Dobruja*, 1845–75.—As suggested above, the earliest railways in the Peninsula were really almost unrelated to it. They comprised a series of links, within the Austro-Hungarian lands, between the

[1] See S. H. Beaver, "The Hellenic electric railway," *Railway Gazette, Electric Traction Supplement*, 5 April 1934, p. 674

[2] Annual statistical volume of the 'Union Internationale des Chemins de Fer,' Paris.

*Flat alluvial plain and barren hills on S.P.A.P. line near Nauplia*

*Trans-Balkan train climbing northern flanks of Stara Planina*

*Locomotive with spark-arrester on 60 cm. line at Rila Monastery*

*Engine shed and harbour at Split. 2–6–6–0 locomotives for Zagreb line, also narrow gauge*

*Double-deck road and railway bridge over Morava east of Kraljevo*

twin capitals of that area and the ports at the head of the Adriatic; and two lines across the north-eastern corner of the Peninsula designed to link the navigable water of the Danube with that of the Black Sea.

The economic necessity for a central European outlet to the Mediterranean is so obvious that it is not surprising that as early as 1825–27 the Hungarian Government considered the possibility of railway construction, and set up a commission which proposed some thirteen lines, the chief of which was to be one from Budapest *via* Sisak (on the river Sava) to the Adriatic coast. A company was actually formed to construct the line, but it failed financially in 1828; the question was later revived and in 1844 another company was formed to build a line from Budapest to Fiume. In the same year however alternative plans for lines of German construction were put forward, with the result that the first railway track in the Balkan Peninsula was actually laid in Slovenia in 1846–47 as part of a through line from Vienna across the eastern end of the Alps *via* Graz and Laibach (Ljubljana) to Trieste, the line being opened throughout in 1850. Ten years later Budapest was linked to this line by a junction at Pragerhof (Pragersko), south of Marburg (Maribor). The obvious routeway provided by the Sava valley between the important towns of Ljubljana and Agram (Zagreb) was utilized by a railway in 1862, but the completion of the second main line, from Zagreb to Fiume, was somewhat delayed owing to the difficulty of crossing the physical barrier between the Sava valley and the Adriatic coast, and to the prolonged litigation regarding the expropriation of some of the valuable forests through which the line had to pass; it was opened in 1875.

Prompted by the success of new methods of communication in western Europe, the Ottoman Government in 1855 announced its intention of encouraging the construction of a railway from Constantinople (İstanbul) to Beograd, but nothing resulted. The need however for better westward communications from İstanbul, and the difficulties of navigation along the last 150 miles of the Danube, including the delta channels, suggested a second plan, for a line from İstanbul to Ruschuk (Ruse) on the Danube, with branches to the Black Sea ports of Varna and Burgas. This great scheme was too much for a first effort and the first line actually built was one, 40 miles in length, across the Dobruja, in what later became Romanian territory, from Cernavoda on the Danube to Kyustenja (Constanţa) on the Black Sea. A concession was granted by the Ottoman Government to a company, financed by British capital and staffed by British engineers, known as the "Danube and Black Sea Railway and Kustendje Harbour Company," and the line was opened in 1860. Then, possibly as part of a scheme for an international west–east line which was to cross the Danube at Ruse, the Ruse–Varna line, 139 miles long, followed in 1866. The same engineers were responsible, but from the first it was a poorer concern than the Constanţa line, and was but flimsily built.[1] No through traffic from western Europe materialized, though a line was opened in 1869 on the Romanian side of the Danube from Giurgevo (Giurgiu), opposite Ruse, to Bucharest (Bucureşti);

[1] In order to avoid the expense of cuttings and embankments the line twists and turns, so closely following the ground surface that 95 per cent. of its track is not on the level, although it runs across a fairly flat plateau.

moreover, little or no harbour facilities existed at Varna, and in consequence the company was on the verge of bankruptcy until it brought off something of a financial coup by selling out to the Turkish Government for £2,000,000. These early lines may be regarded as an expression of the efforts of British commercial interests to capture Balkan trade after the Crimean War; it is interesting to realize that both of them may possibly play a part in Germany's war effort by transporting Russian oil; indeed the Germans have been trying for some time to persuade the Bulgarians to double the Varna line, though it would appear that this has not yet been accomplished.

*The Orient Express routes*, 1869–88.—This period represents the time occupied by the construction of the main east–west and north–south trunk lines across the Peninsula, which have become known as the Orient Express routes. Negotiations inspired by the Sultan Ali Pasha between the Turkish Government and the principal financial powers in Europe resulted, after almost a decade, in the granting of a concession in 1869 to an international financier, Baron Hirsch, Bavarian by birth and with extensive business connections in Paris and Vienna. A company was formed, known as the "Société impériale des chemins de fer de la Turquie d'Europe," to build certain lines of railway. The main line was to run from İstanbul *via* the Maritsa valley, Sofiya, Priština, Novi Pazar, and Sarajevo to Doberlin (Dobrljin) on the Turkish–Austrian frontier, whence Austrian construction would have continued it to Sisak and so linked Turkey *via* Zagreb with Vienna; branches were to be built from Priština northwards to the Serbian frontier and southwards to Salonika, from Philippopolis (Plovdiv) to Burgas, and from Adrianople (Edirne) to Yambol, on the Burgas line, and to the Aegean shore at Enos or Dedeagach (Alexandroupolis). The non-inclusion in this scheme of the obvious Morava valley routeway, leading to Beograd and the Sava and Danube valleys, is interesting; it is due to the existence of the independent kingdom of Serbia, which could not make up its mind whether it wanted railways or not, and to the natural desire of the Turks to keep as much as possible of what was to be a great international line within their own territory. For twenty years, from 1851 onwards, discussions in Serbia were frequent, the pros and cons being that railways would assist economic development but on the other hand would render the country more liable to invasion by either Turkey or Austria.[1] All kinds of plans were put forward for a Serbian railway system by Austrian, German, French, and British authorities, and one rather extraordinary British proposal was for a line from Beograd to Scutari (Shkodër).

The death of Ali Pasha in 1871 caused an alteration in the plans, for his successor, Mahmud Pasha, objected for political reasons to the union of Turkey with the central European railway system, preferring links with Romania and Russia. Hirsch abandoned his concession, and the company which had been formed to operate the railways which he built, the "Cie. générale pour l'exploitation des chemins de fer de la Turquie d'Europe," subsequently known by the simpler title, "Oriental Railways Company," undertook to complete certain sections only of the original scheme. In view

[1] See D. Arnaoutovitch, 'Histoire des chemins de fer Yougoslaves,' Paris, 1937, pp. 38–54.

of the complete absence of any means of transporting materials into the interior, construction advanced necessarily from the termini; by 1874 the main line had progressed from İstanbul to Belovo, about 40 miles west of Plovdiv, and branches had been laid from Edirne to Alexandroupolis, and from Tarnovo-Seimen (Zlati-dol) across the rich arable plain of Zagora to the grain-growing centre of Yambol. In addition, the railway had penetrated up the Vardar valley, from time immemorial one of the main avenues of communication in the Peninsula, from Salonika *via* Üsküb (Skoplje) and across the famous Kosovo Polje to Mitrovica. It was intended to push on with the construction of a trans-Balkan line from Yambol to join the Ruse–Varna line, but nothing came of this, and it is only now, nearly sixty years later, that such a line is actually nearing completion. At the western end of the projected trunk line the Dobrljin–Banja Luka section was begun in 1872, but there was no other railway near, and the difficulty of getting materials led to its abandonment two years later; it was completed in 1879 as a military line after the occupation of Bosnia by the Austrians. This curious relic of the original Hirsch concession remains to this day the only standard-gauge line in Bosnia.

The wars of 1876–78 further upset the framework of the Turkish plan, for the new frontiers which were set up after the conflicts severed Bosnia and Hercegovina from Turkey, cut off the northern extremity of the Salonika–Mitrovica line, and cut the İstanbul–Plovdiv line in two, west of Edirne. Austria supplanted Turkey as the moving spirit in railway planning. The early lines in the Peninsula, running inland from the ports of Varna, İstanbul, Alexandroupolis, and Salonika, had opened up a considerable part of Turkey to British seaborne commerce; to the detriment of the Austrian trade which was carried down the Danube. In the late 'seventies Lancashire textiles had almost a monopoly in Turkish markets, and even after the Austrian occupation of Bosnia, English goods imported *via* the Salonika–Mitrovica railway could undercut Austrian products in the Bosnian markets. The Austrian eagerness to complete the European ends of the Orient lines can therefore be easily understood. Austrian designs were furthered by Serbia who, seemingly abandoned by Russia in the latter's creation of the Big Bulgaria of the San Stefano Treaty of 1878, fell into the lap of Austria-Hungary before the Congress of Berlin, and remained very much under the influence of Vienna until the Great War liberated all the South Slav peoples. In a convention between Serbia and Austria-Hungary in July 1878 the former agreed to build a line up the Morava valley from Beograd to Niš, forking thence, one line continuing southwards up the Morava valley to the former Turkish frontier at Vranje, the other running south-eastwards up the Nišava valley to the Bulgarian frontier beyond Pirot; Austria agreed to link up the Austro-Hungarian system with these Serbian lines by new construction which would end with a large bridge over the Sava between Semlin (Zemun) and Beograd. Then in 1881 the "convention à quatre" (consisting of representatives of Austria-Hungary, Serbia, Bulgaria, and Turkey) set up by the Congress of Berlin, made final provisions for the completion of the new international line through Bulgaria, the route chosen being from Belovo through Ihtiman, Sofiya, and the Dragoman Pass. The Bulgarians would have preferred the

original route westwards from Sofiya into the region of Skoplje, for such a line would have passed through their only significant coalfield, at Pernik, and through a valuable agricultural region in the Kyustendil basin; in addition, and perhaps more important, it would have facilitated the penetration of Bulgarian political, economic, and cultural influences into northern Macedonia. Macedonia has always been regarded by the Bulgarians as part of their "living space" ever since the first Bulgarian Empire extended over the area in the tenth century; moreover the territory had actually been assigned to them by the Treaty of San Stefano in 1878, but had been snatched away again in the Berlin Treaty of 1881 at the instance of the western powers who feared Russian influence on the fledgling state.

The completion of the international line, scheduled for 1886, took longer than was expected, the Bulgarian section being especially delayed by a minor frontier war with Serbia in 1885 and by the revolution in Eastern Rumelia in the same year, but eventually all the missing links were constructed, and in 1888 through communication was possible from Beograd to Salonika and İstanbul. The first-named route followed the upper Morava valley south of Niš, crossing the Danube–Aegean watershed at no more than 1400 feet above sea-level, and joining the already existing Vardar valley line at Skoplje. Meanwhile the Hungarians had been very busy north of the Danube, and the Budapest–Maria Theresiopel (Subotica)–Neusatz (Novi Sad)–Beograd line was completed, including two large bridges, one across the Danube at Novi Sad and the other across the Sava at Beograd, in 1884. An inaugural train left Budapest on 12 August 1888 and duly arrived at İstanbul, and the service which ran regularly thereafter reduced the journey time between the two capitals from fifty-six hours (*via* Bucureşti and Giurgiu, by ferry across the Danube to Ruse and thence by train to Varna and by Black Sea steamer) to thirty-eight hours (without a change); whilst the Beograd–İstanbul time was reduced from ten days by road to thirty hours by rail. A daily connection was established each way from Vienna to Salonika and İstanbul, the average speed of the trains being about 21 miles per hour. The Hungarian State Railways were given the responsibility of arranging the international traffic, which soon showed itself to consist mainly of passengers and mails, freight traffic being of necessity meagre in view of the primitive economy of the countries through which the lines passed. There was a possibility that Salonika might develop as a port on a new short route to the Far East *via* the Suez Canal, but such a function was dependent on the provision of better port facilities and the establishment of a packet service across the Mediterranean, and these never actually came into being.

Austrian commercial influence in the Peninsula expanded rapidly in and after the 'eighties, especially in Serbia. Although, as Arnaoutovitch has shown,[1] freight rates on goods entering Salonika from western and west-central Europe were appreciably lower if sea transport from Bremen, Hamburg, Marseilles, or Trieste were employed than if an all-rail route were used, the lack of through rates on the Salonika–Beograd line and the great assiduity of Austrian and German commercial travellers began to prove a fairly effective barrier, for example to French goods.

[1] *Op. cit.*, pp. 197–9.

*Bosnia, Hercegovina, and Dalmatia, 1880–1900.*—The entry of Austria into Bosnia and Hercegovina in 1878 paved the way for the development of an entirely new railway system, which was begun with great urgency almost immediately the occupation had been effected. The fortress of Slavonski Brod, on the Sava river, was chosen as a supply headquarters, being the only point on the whole frontier approached by a railway (the newly constructed line from Subotica *via* Vinkovci, which was later to become part of a main international route). A bridge was thrown across the river to Bosanski Brod, which thus became the railhead of the new system. So great was the hurry to push on with railway construction for military and administrative purposes that there was no time for long deliberations on the question of gauge and equipment, and since some 76 centimetre (2 feet 6 inches) gauge material happened to be available at the time, a beginning was made with that material, and the whole system thus came to be built on this gauge, though parts of the road-bed were prepared for standard-gauge track which it was intended ultimately to lay. In four years the line reached Sarajevo. The southern half of the trunk line was commenced from the small port of Metković, near the mouth of the Narenta (Neretva) river, the navigation of which had been improved to take vessels up to 700 tons in 1882. The line ran up the wild Neretva gorge to Mostar, which was reached in 1885, but the last section, including a summit of 2800 feet, was most difficult and was not completed until 1890; it contained a section graded at 1: 16 which had to be worked by rack and pinion. The inadequacy of Metković to serve as a main port for Bosnia prompted the extension of the line to Gravosa (Gruž), the port of Ragusa (Dubrovnik), and a further prolongation to Zelenika on the northern shore of the Gulf of Cattaro (Kotor). Spalato (Split) was also visualized as an outlet, and it was intended to link up the already existing lines at Split and Sebenico (Šibenik), constructed in 1875, with the Bosnian trunk line; a branch was begun from the latter line at Lašva, passing through difficult country in a south-westerly direction, but after reaching Bugojno by 1894 further construction was suspended owing to lack of funds, and there the terminus has remained ever since, Split being later approached from quite another direction.

Several branches were thrown off from the trunk line, including three built to tap mineral resources (Simin Han—lignite, Vares—iron ore, and Čevljanovci (Ivančići)—manganese); but the most interesting was the strategic line which ran through very difficult terrain (the works included about a hundred tunnels and many bridges) south-eastwards from Sarajevo to the frontier of the Sandjak of Novi Pazar. Although of military origin this line, which was built to receive standard-gauge track but was laid with 76 centimetres like the rest of the system, was visualized by the Austrians as part of a through route to Salonika *via* Mitrovica. It would have avoided Serbian territory, effectively separated the South Slav peoples of Serbia and Montenegro, and attracted to Salonika the international and Far Eastern mail traffic which then went by a longer route through Italy to Brindisi (for Suez). This grand scheme may be discerned as part of the Teutonic "Drang nach Osten" policy; it never materialized, for in the early years the Hungarians objected because the line would have injured the through traffic of Budapest, whilst later the Austrians

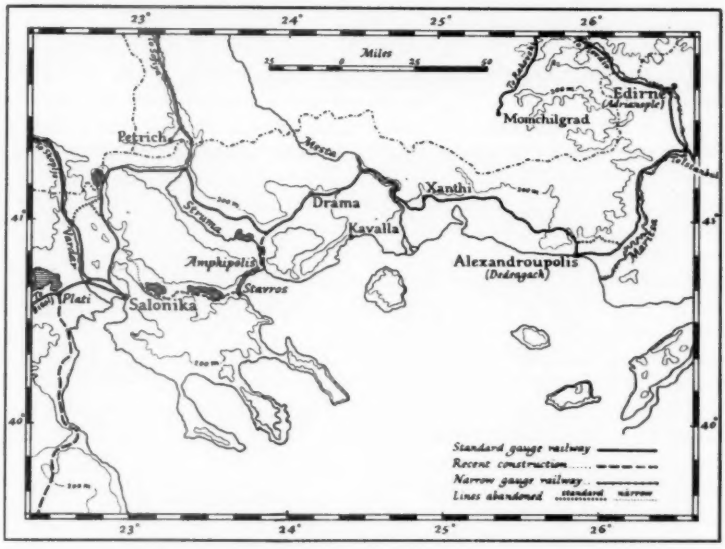
hesitated to press the Turks for a concession in view of the opposition which would have been aroused in political and economic circles in Britain, France, and Italy.

*The former Hungarian lands*, 1880–1900.—In Slavonia and Syrmia (Srem), between the Sava and Drava rivers, and in the area north of the Danube, consisting of the Bačka and Banat plains separated by the meandering course of the river Theiss (Tisa), a considerable mileage of railways was constructed, mainly during the last twenty years of the century. One can hardly call it a network or a system, for it consisted for the most part of a number of scattered, disconnected and independent lines of purely local interest, the development of which was encouraged by the exceptionally favourable Hungarian laws relating to local railways.[1] No main line followed any of the four main rivers—Sava, Drava, Danube, and Tisa—for each was itself navigable and the railways tended to connect the small towns with each other and with the river ports. The main line from Beograd to Budapest, completed in 1884, followed roughly the centre of the Danube—Tisa interfluve between Novi Sad and Subotica; the only other "main" line was that from Subotica to Slavonski Brod, previously referred to in connection with the Bosnian lines. This was continued during the 'eighties up the Sava valley to Sisak (for Zagreb). The Vinkovci–Sremska Mitrovica link in the early 'nineties completed the Beograd–Zagreb route, but no through traffic followed this line until after the union of the South Slav peoples in 1918, when it became a major European artery.

*Greece*, 1881–1900.—The physical nature of Greece did not attract the railway builder, and the division of the country into small compact regions separated by the sea or by mountain ranges favoured the growth of small isolated lines rather than a network or system. Moreover the country was politically and economically backward, and donkeys and small coasting vessels were adequate transport media for its needs. Apart from the short line connecting Athens and Piraeus, laid in 1869, there was no railway building until 1881, in which year Greece, after acquiring new territory in Thessaly, appeared to wake up to the necessity of keeping abreast of developments in other parts of Europe, and employed a French public works mission to plan a road and railway net and new harbour works. As a result of this, concessions were granted for most of the lines which at present exist, and a period of intensive construction began. Within a decade five separate lines, all on the metre gauge, were completed or well in hand. The short line from Pirgos to the small port of Katakolon, only 8 miles distant, had as its main purpose the serving of part of the rich agricultural plain of Elis, the chief currant-producing area of Greece. The Attica railway connected Athens with the lead mines of Lavrion. The Thessalian lines, which were in the first instance of

[1] *Cf.* Arnaoutovitch, *op. cit.*, pp. 23–28, where the text of the law is given; local railways were allowed for example to utilize the sides of the roads, or the dike embankments, for their track; they were not obliged to have telegraphic signalling or even to provide a daily passenger train, though they were compelled to carry the mails; they were exempt from stamp duty on their legal documents; an annual sum was set aside by the government for their assistance. The curious thing is that most of them were standard gauge and not narrow gauge as might have been expected from a study of western European examples of similar developments.

military significance only, linked the agricultural plains of Thessaly to the small port of Volos. The north-western railway connected Krioneri, a small port on the Gulf of Corinth opposite Patras, with Agrinion, and was built mainly for the transport of agricultural produce including tobacco. The most important of these early lines however was the "S.P.A.P.," or Piraeus–Athens –Peloponnese railway, the main line of which ran from Piraeus through Athens and along the coast, crossing the Corinth Canal by a bridge, to Patras, continuing thence quite close to the western coast of the Peloponnese as far as Kiparissia, and sending a return line across the peninsula *via* Tripolis and Argos back to Corinth. Several branches were given off, as from Pirgos to




*Salonika and Constantinople Junction Railway*

Olympia (for tourist traffic) and to serve the small ports of Kalamata and Nauplia. The two sections of the railway contrast markedly, the coastal section being easily graded, if somewhat sinuous, that across the interior having the characteristics of a mountain railway, with summit levels of just over 1000 feet between Corinth and the head of the Gulf of Nauplia, and of 2672 feet in the heart of the peninsula south-west of Tripolis, and frequent gradients of 1 in 50 or even steeper.

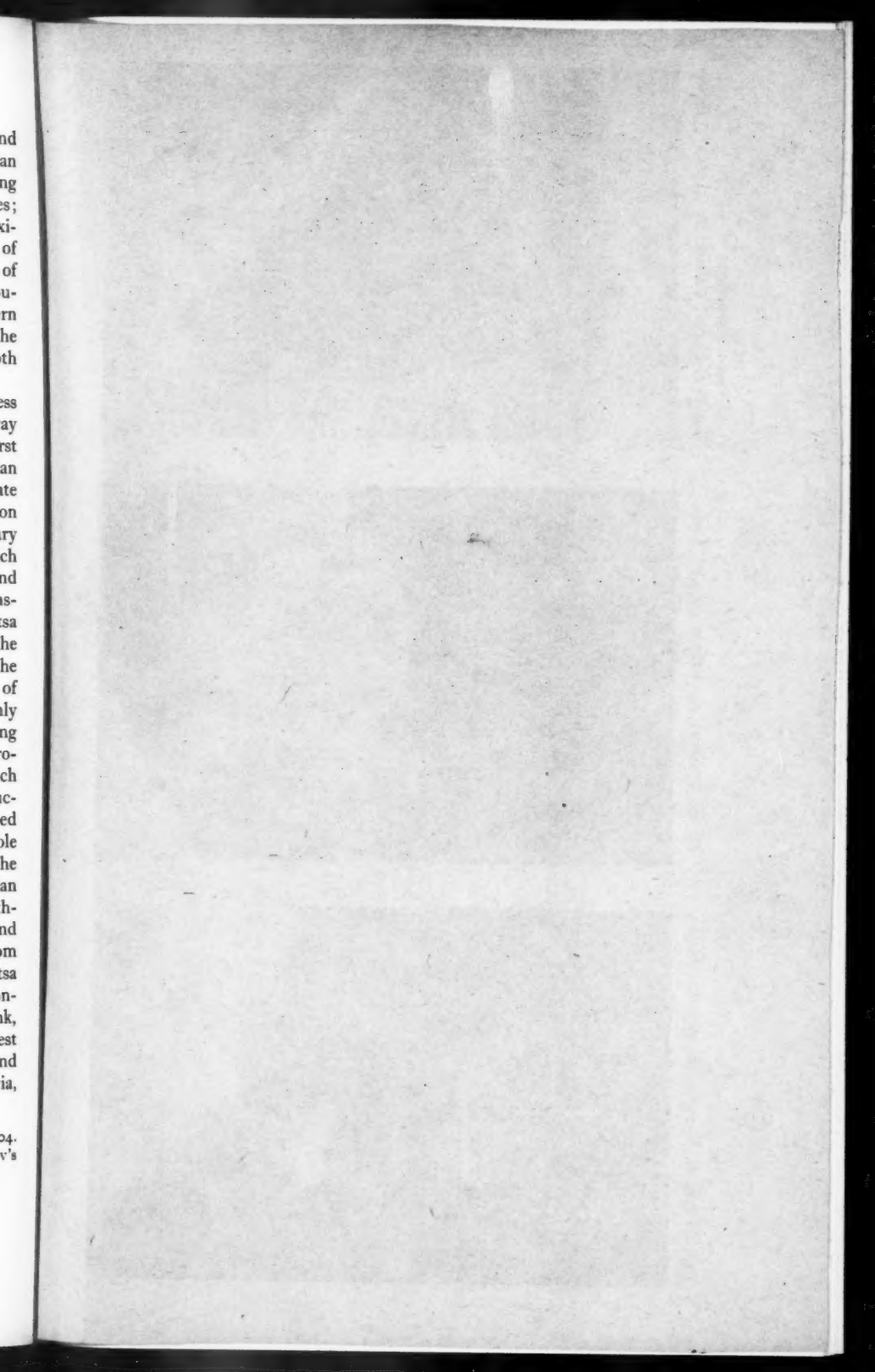
By 1900 there were about 700 miles of railways in Greece, of which the S.P.A.P. claimed 472 miles. Another line which was planned in the early 'eighties was the Piraeus–Larisa line, but this was a larger and more difficult undertaking and the century had ended before it began to take shape.

*Turkey*, 1890–1900.—Salonika was the centre of two developments, both essentially strategic in character, towards the end of the century. The 136-mile line *via* Vérria and Flórina to Monastir (Bitolj), in Macedonia, was built

by a German firm in 1890–94. The 325-mile line known as the Salonika and Constantinople Junction Railway, financed by Turkish and Franco-Belgian banks, was built in 1892–95. It is rather a tortuous line, alternately crossing wide and fertile plains, famous for tobacco, and barren mountain ranges; there are two hundred and fifty bridges and thirty tunnels, and the maximum gradient is 1:40. The line was laid at a minimum distance of 20 kilometres (12 miles) from the coast so as to be well beyond the range of naval bombardment, and moreover the two ports of Salonika and Alexandroupolis were by-passed in case they should fall into hostile hands. The western by-pass, behind Salonika, linked the line with the Orient line to Skoplje; the eastern one, behind Alexandroupolis, linked it with the line to Edirne. Both these by-passes have now been abandoned.

*Bulgaria*, 1888–1900.[1]—The completion of the international Orient Express line through Bulgaria marked the end of an important epoch in the railway history of that country. The last decade of the century witnessed the first stages in the creation of a national railway system. In 1888 the Bulgarian parliament, which four years earlier had declared itself in favour of a state railway policy—a wise, if obvious move in view of the poor economic position of the country which rendered impossible the local raising of the necessary capital—embarked upon an ambitious programme, the main points of which were the construction of a trunk line from the Turkish frontier *via* Sofiya and across the northern foreland or Danubian platform to Varna, and a trans-Balkan connection between this line and the international line in the Maritsa valley. A large loan was raised abroad in 1892 and work commenced. The long east–west line from Sofiya to Varna followed the Isker gorge through the Balkan ranges and then struck eastwards across the rich agricultural lands of the Danubian platform to join the Ruse–Varna line at Kaspichan. The only obstacles in this northern foreland were the deeply incised northward-flowing streams which had to be bridged. The valleys of these streams however provided natural routes for branches to the small Danube ports, and one such branch, from Somovit to Yasen, was built first in order to enable the construction of the main line, supplied with German and Austrian materials shipped down the Danube, to proceed in the middle as well as at both ends. The whole line was completed in 1897 and quickly began to play an important part in the transport of grain to the export ports of Varna and Ruse and to the urban market of Sofiya. Other lines begun at this time include that running south-westwards from Sofiya, which in 1893 reached the lignite field of Pernik and thus rendered its exploitation possible; the so-called Parallel line from Plovdiv across the northern part of the rich agricultural land of the Maritsa lowland to Nova-Zagora on the Yambol line (which in 1890 had been continued to the Black Sea port of Burgas); and the main north–south link, which advanced from Ruse to Gorna-Orehovitsa, centre of one of the richest agricultural areas in the country, with vineyards and market gardens, and continued a few miles beyond to Tarnovo, a former capital of Bulgaria, which was to be the starting-point of the great trans-Balkan line.

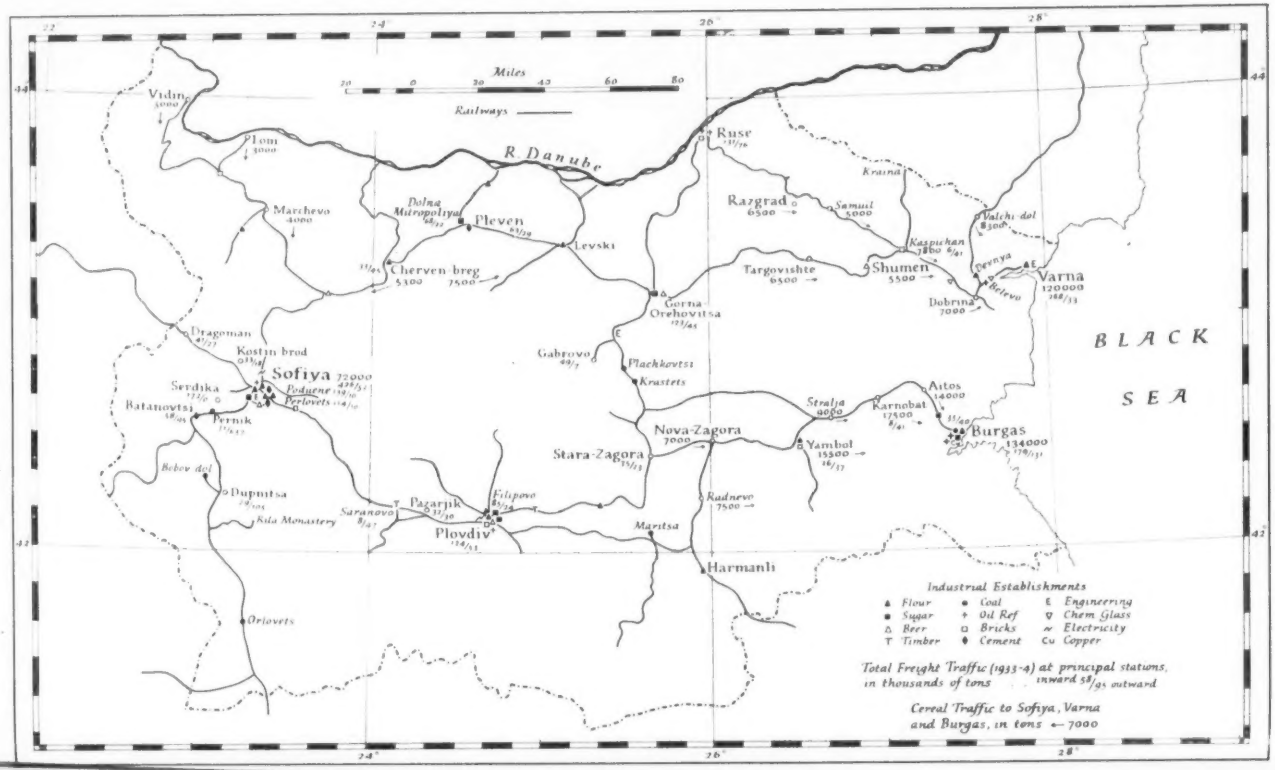
[1] See S. H. Beaver, "The Bulgarian state railways," *Railway Gazette*, 64 (1936) 1204. Much useful information, in the Bulgarian language, is summarized in Ivan Dorossiev's 'Istoriya na zheleznitsite,' Sofiya, 1935, especially pp. 118–41.



*Trans-Balkan goods train burning lignite*

*76 cm. Chepino line in the Eli-dere gorge*

*Simplon-Orient Express at Athens. Powerful 2-10-0 locomotive*


Miles
20 0 20 40 60 80
Railways
R. Danube
Vidin 30000
Lom 30000
Ruse 35/36
Kraina
Razgrad 6500
Samuil 5000
Valchi dol 8300
Kaspichan 1800 6/41
Marchevo 4000
Dolna Mitropoliya 68/37
Pleven 83/39
Levski
Cherven-breg 5300
7500
Targovishte 6500
Shumen 5500
Pernya
Varna 120000 268/33
Beloslav
Dobrina 7000
Gorna Orehovitsa 123/45
Dragoman 47/37
Kostin-brod 33/36
Sofiya 72000 429/51
Gabrovo 49/7
Plachkovtsi
Krastets
BLACK SEA
Srednika 7250
Foduene 118/16
Perlovets 114/16
Batanovtsi 18/45
Pernik 117/43
Stralja 8000
Karnobat 17500 8/41
Aitos 14000
Burgas 134000 178/131
Nova-Zagora 7000
Stara-Zagora 175/13
Yambol 15500 16/17
Bebov dol
Dupnitsa 28/105
Rila Monastery
Saranovo 8/47
Pagarjik 37/30
Filipovo 85/28
Plovdiv 134/53
Radnevo 7500
Maritsa
Harmanli
Orlovets
Industrial Establishments
▲ Flour ● Coal E Engineering
■ Sugar + Oil Ref ▽ Chem Glass
△ Beer □ Bricks ~ Electricity
T Timber ♦ Cement Cu Copper
Total Freight Traffic (1933-4) at principal stations, in thousands of tons inward 58/95 outward
Cereal Traffic to Sofiya, Varna and Burgas, in tons ← 7000
22° 24° 26° 28°
44° 42°

*The period of expansion before the Balkan Wars, 1900–12*

*Bulgaria.*—This great expansion led Bulgaria into serious financial difficulties, and railway building was at a standstill for half a dozen years, until in 1905 a beginning was made with the most pressing need of the time, the connection across the Stara Planina or Balkan range. Three separate routes were proposed—a good commentary on the relative ease of crossing the range. The first was *via* Gabrovo, an important textile manufacturing centre, and across the famous Shipka Pass to the Tunja valley at Kazanlak, the centre of the attar of roses industry, and thence across the Sredna Gora upland to Stara-Zagora, centre of a rich agricultural region, on the Plovdiv–Burgas Parallel line. The second was a more easily graded route *via* the Hanikoi Pass to Nova-Zagora, and the third, farther east and not leading quite in the required direction, through the Elena basin and across the mountains to Sliven. Actually none of these routes was adopted, the choice finally falling on the most direct route possible, from Tarnovo to Stara-Zagora, which, although involving severe grades and heavy constructional works, including a spiral ascent on the gentler northern flanks of the range, which is crossed at about 3300 feet above sea-level, and a complete figure-of-eight, mainly in tunnels, on the much steeper southern side, passed through a small coal deposit at Plachkovtsi. Eight years were occupied in building 90 miles of line, and the trans-Balkan crossing was completed only in 1913.

During this period also the western line through Pernik was completed as far as Gyueshevo on the Turkish frontier; this line was in part intended to serve as a link between Sofiya and the Salonika–Skoplje line, but the Turks did not desire Bulgarian penetration into this region, and no connection has ever been made with Skoplje. The line did however provide the agricultural region of Kyustendil with an outlet, *via* Sofiya, to the Danube and the Black Sea. Two more Danube outlets were begun during this period: the Levski–Svishtov line was completed in 1909, but the Mezdra–Vidin line was interrupted by the wars.

*Greece.*[1]—The main north–south trunk line through eastern Greece began to take shape in 1902, when work was commenced by the Batignolles Company of Paris, backed by Paris financiers, on the 246 miles of line from Piraeus to the Turkish frontier at Pappapoúli, whence steamer connection would be made with Salonika. It was a difficult line to build, for mountain ranges, crossable only by rocky gorges, alternated with broad expanses of soft alluvial plains, often badly drained. There are fifty-eight tunnels on the line totalling over $6\frac{1}{2}$ miles in length, and over one hundred and fifty viaducts and bridges, many of imposing proportions. The ruling grade is 1 : 50, but on some of the ascents 1 : 62 is the steepest. Between Athens and Larisa the line has four considerable climbs, with intervening drops almost to sea-level; it rises to 1148 feet on the Parnes-Pentelicon col, to 705 feet before Thebes, to 1342 feet on the north-east flank on Parnassus, and to 1919 feet over the Othrys range between the Sperkhios plain and the plain of Thessaly; after crossing this plain it finds its way through the Vale of Tempe and runs along the coast at the foot of Olympus. It was completed in 1909, but could hardly

[1] B. L. Leoudopoulos, "The Hellenic state railways," *Railway Gazette*, 56 (1932) pp. 334–38.

perform its proper function as an international link until the intervening section through Turkish territory had been built, and this was only possible after the Balkan Wars had removed Turkish control of the area in question. The only other event of note during this period was the electrification of the Athens–Piraeus line in 1904.

*Serbia.*—The turn of the century was a period of stagnation in railway building in Serbia. The State had taken over the railway system, consisting of some 330 miles of track, in 1889, but little development took place until the rejuvenation of the country which accompanied the ascent to the throne of Petar Karadjordjević in 1903. Between this date and the Balkan Wars two main plans were uppermost. The first was the establishment of an east–west narrow-gauge line (built on the 2 feet 6 inches gauge in the hope of eventually linking it with the Bosnian lines). The line from Paraćin in the Morava valley on the Orient line to Zaječar in the Timok valley was opened in 1912; in addition to performing a useful function in the linking of the two valleys it assisted the development of the rich copper mines of Bor and Vrška Čuka. Another line from Stalać, higher up the Morava valley, westwards to Kraljevo and Užice, was also completed in 1912, bringing the railway into a region rich in agricultural resources and scenic beauty. A third line leading westwards ran from Mladenovac on the Orient line to Valjevo. The second plan was a grand scheme for opening up the north-eastern corner of Serbia and at the same time paving the way for a possible link with Romania and Russia (a link greatly desired in view of the "encirclement" of Serbia by Austria and Turkey) and a trans-Balkan line from the Danube to the Adriatic. A great international company, with financial backing from France, Italy, and Russia, was formed to make a trunk line from San Giovanni di Medua (Shëngjin) on the Adriatic coast to Djakovica, Priština, and Serbia, and the Serbs began work on the north-eastern end of the line between Prahovo, on the Danube, and Zaječar. The wars put an end to the scheme, but the Serbian section was later completed.

*The wars*, 1912–18.—The Balkan countries had not recovered from the conflicts against the Turks and between themselves in 1912–13 when the disaster of 1914 overtook them. Serbia, of course, suffered most. After performing prodigious feats, considering their meagre equipment, in transporting the Serbian armies to the various scenes of the war against the Austrian and later Bulgarian aggressors, the railways were systematically destroyed by the retreating Serbians in October and November 1915. Bridges were blown up, tunnels dynamited, track torn up, and rolling stock rendered useless.

In Bulgaria, the line planned to tap the grain-growing area of the Dobruja for the port of Varna was rendered almost useless for that purpose by the interposition across its track of the new Romanian frontier after the second Balkan war of 1913. The line was actually completed on the Romanian side to join the Cernavoda–Constanța line in 1915 but the political frontier was an effective economic frontier also, and Varna benefited but little. The recent (August 1940) readjustment of the frontier may have done something towards the amelioration of this situation. During the Great War there was little fighting in Bulgaria except in the south-west, where a military line of

2-foot gauge was built with German materials, down the Struma valley from Radomir, on the Kyustendil line, to the Salonika–Alexandroupolis line at Demirhisar. When the Bulgarians retreated in 1917 they tore up the track at the southern end of the line, and since the post-war frontier was drawn across the Struma valley at Kula the connection with the Greek line has not been replaced. The line has proved useful however as it taps two small lignite fields at Orlovets and Bobov-dol and runs through a rich tobacco-growing region. Two other narrow-gauge lines were also built during the war, one from Kaspichan to Kraina, in the Deli-orman region, and the other from Cherven-breg, on the Sofiya–Varna line, to Bela-Slatina (later continued to the small port of Orehovo on the Danube). All these narrow-gauge lines were taken over by the Bulgarian State Railways after the war.

The revised frontier of Greece after the Balkan wars left the way clear for the completion of the Athens–Salonika line by the construction of the section from Pappapouli to Plati (on the Salonika–Bitolj line). This was completed in 1916, but owing to the Great War Athens remained effectively cut off from Europe until the inauguration of the Simplon–Orient Express service in 1920. A short narrow-gauge line, 42 miles long, was built by the British army across the neck of the Chalcidice peninsula from Sarakli to the small port of Stavros.

*Since* 1918

*Yugoslavia.*[1]—The Serb-Croat-Slovene State in 1918 was faced with problems of communication greater than those of any other country in Europe. The only country in anything like a comparable situation was Czechoslovakia which, like Yugoslavia, inherited bits and pieces of the Austro-Hungarian railway system, the main characteristic of which was that it concentrated on Vienna and Budapest. Yugoslavia's problem may be summed up in three points: in the first place the greater part of the Serbian railway system had been destroyed or rendered quite unusable. Four months after the Armistice the main trunk line was workable, and in ten months all the lines had been rendered provisionally serviceable, but much reconstruction of bridges and other works remained to be done. Secondly, the frontiers were not drawn with much regard for the railways: in the north-west corner, Italy took the main outlets of Trieste and Fiume; in the south-west, independent Albania stood in the way of the realization of the great south-west–north-east trans-Balkan line; in the north the lines focused on Vienna and Budapest. Yugoslavia acquired some 5600 miles of line from Austria-Hungary, of which nearly 1900 miles were small private lines of local interest, mainly in the former Hungarian lands (Croatia, Slavonia, and Vojvodina) which had to be bought out. Thirdly, the Austrian policy, copied from the Turks, of "divide et impera" had left the south Slav lands with no intercommunication. Croatia was not linked to Bosnia, nor Bosnia to Serbia; the Banat was separated from Serbia by the uncrossed Danube and from the Bačka by the similarly unbridged Tisa. The Sandjak had no railway at all, Montenegro but one insignificant narrow-gauge line, and Hercegovina, Dalmatia, and Macedonia only one trunk line each.

A conference held in May 1920 decided on a general plan of construction

[1] Arnaoutovitch, *op. cit.*, pp. 233–82.

and reconstruction; the plan became law in July 1922 and work then proceeded rapidly for some years. The realization that the plan was not entirely perfect, combined with the financial stress of the Great Depression, brought about numerous modifications, but the plan and its accomplishment may be briefly summarized.

Of prime importance was the transformation of the Ljubljana–Zagreb–Beograd–Niš–Caribrod line, and its Niš–Djevdjelija branch, into first-class international routeways, thus providing a new and more direct route to İstanbul avoiding German, Austrian, and Hungarian territory. The first Simplon-Orient Express left Paris for İstanbul on 15 April 1919, taking ninety-six hours over its journey. The reconstruction in Yugoslavia, and in particular the doubling of the track between Novska and Beograd, was largely responsible for reducing this figure a few years later to fifty-seven and a half hours. The Salonika–Athens portion of the Express began to run in July 1920. Another line of international significance was that from Vinkovci to Subotica which, after the construction of a large bridge across the Tisa at Senta in 1923 began to be used by a Bucureşti portion of the Simplon-Orient train. Thus about 1000 miles of Orient Express routes lie within Yugoslavia. Of more national importance was the Zagreb–Sušak line, which was largely reconstructed as a result of the development of Sušak as Yugoslavia's main Adriatic outlet.

The inadequacy of the port of Sušak and of the tortuous narrow-gauge Bosnian lines leading to Split and Dubrovnik to deal with all Yugoslavian seaborne foreign commerce led to the improvement of the small port of Bakar, a few miles south of Sušak, and to the construction of a new standard-gauge line, known as the Lika line, continuing one already started for strategic purposes by the Austrians, from Ogulin (on the Zagreb–Sušak line) to Split, following from Knin to Split and Šibenik the old narrow-gauge line, built in 1875, which was so worn out that the rails, when removed, scaled only two-thirds of their original weight. Thus Croatia and Dalmatia were linked, and although the line was twice as long as the Zagreb–Sušak stretch it led to a port well removed from Italian influence (for it must be remembered that Sušak and Fiume are separated only by a steel fence which runs through the town).

The eastern extremity of the Bosnian 2 feet 6 inches gauge system at Vardište was separated by only 35 miles of rather difficult country from the western end of the Serbian system at Užice, and the two ends were joined in 1925, the works including the Šargan tunnel nearly a mile long. Thus Bosnia and Serbia were at last linked, and the installation of a narrow-gauge track alongside the main trunk line in the Morava valley from Paraćin to Stalać rendered the east–west narrow-gauge line complete from Dubrovnik to Zaječar. Beograd however was still without direct communication with Dubrovnik, and so two sections of new narrow-gauge line were added in order to complete the connection, from Čačak to Lajkovac in 1920–22, and from Obrenovac to Beograd in 1928. The separation, by wide rivers, of the Banat from the Bačka, and of the former from Serbia, was overcome by some notable bridge building. The Senta bridge has already been referred to. Lower down the Tisa a new bridge at Titel provided a further Bačka–Banat

link, but the *pièce de résistance*, one of Europe's great bridges, is that over the Danube between Beograd and Pančevo, completed, with a new line of railway and much reclamation of marshes, in 1935. A notable achievement in 1931 was the completion of the Ibar valley line from Kragujevac to Mitrovica, which provides an alternative route from Beograd to Skoplje, avoiding the important international line through Niš.

Southern Serbia (Serbian Macedonia) was very poorly served by railways, having but one trunk line down the Vardar valley. In view of the mixed character of the population and of the strength of the Bulgarian irredentist movement the Yugoslavs have devoted considerable attention to the improvement of communications in this region, and the scheme is not yet complete. Veles was chosen as the point of embranchment for two standard-gauge lines, one running eastwards to Štip and Kočane, which is intended to return to Veles *via* Strumica, and the other a much more spectacular line, including on the Veles–Prilep section eighteen tunnels, one of them over 1½ miles long, south-westwards to Bitolj. This replaces a wartime narrow-gauge line. Another wartime narrow-gauge line built by the Germans (on the 2-foot gauge, *cf.* the Bulgarian Struma valley line) ran from near Skoplje to the shores of Lake Ohrid, and this has been remodelled, retaining its 2-foot gauge.

Mention must finally be made of a number of grandiose schemes for international and trans-Balkan lines, only parts of which have been completed. A new link with Romania is planned in a line leading from Beograd to the Iron Gates of the Danube near Turnu Severin. Only the western half of this has been completed, but the Beograd–Mala Krsna section and its connection to Velika Plana provide a useful relief for the rather congested main Orient line. Farther south, a great scheme for linking the eastern corner of the Adriatic with Romania is simply a revival of an old idea. The northern end of the line has been completed, from Prahovo to Niš (though there is as yet no bridge over the Danube to link up with the Romanian lines) and two sections in the middle are complete, one running south-westwards from Niš and the other from Priština to Peč. The south-western end however, across the Montenegrin mountains, presents enormous physical difficulties, and it may be doubted whether it will ever come into being.

There are still large gaps in the Yugoslavian railway map. For the most part there are schemes in plenty to fill these gaps, but the difficult terrain, sparse population, and meagre traffic prospects may deter their accomplishment for a long time.

*Greece.*—Unlike Yugoslavia and Bulgaria, Greece has developed but little new railway mileage since the Great War. The country is of course fundamentally unsuited to the development of a railway network, and moreover the growth of road transport has even made some of the existing lines unremunerative. Thus the S.P.A.P. line has recently gone into liquidation and its working has been taken over by the State Railways. The latter were formed in 1920 from the fusion of the Hellenic Railway (the Piraeus–Salonika line), the Salonika and Constantinople Junction Railway, and the German-owned Salonika–Bitolj line, giving a total standard-gauge mileage of close on 750. A standard-gauge link between Vérria, on the Bitolj line, and the Thessalian railway terminus at Kalabaka, has been under construction by a Belgian firm

for some years, but is not yet complete. The only important line to be completed is a short branch from the Thracian line to Amphipolis, a new port at the mouth of the Struma river.

*Bulgaria.*—A considerable mileage of railway has been constructed since the Armistice, despite the comparative poverty of the country, and as in Yugoslavia there are numerous schemes for covering the country with a network which its economic condition hardly warrants. The main plan, is for a sub-Balkan line to connect the series of elongated basins which lies at the foot of the great fault-line scarp of the Stara Planina, from Sofiya through Pirdop, Karlovo, and Kazanlak to Sliven (and so to Burgas). Some parts of this have been opened, notably in the Tunja valley, and only the stretch between the eastern end of the Sofiya basin and Sopot, near Karlovo, remains to be built. Secondly, a very useful, if difficult piece of construction has brought the railway to the Arda valley in the south, from Rakovski on the Orient line to Momchilgrad. This is the great silk-producing area of Bulgaria. Thirdly, there are several projects for new trans-Balkan lines, one of which, from Shumen to Karnobat *via* Asparuhovo, should by this time be nearing completion. Fourthly, the narrow (2 feet 6 inches) gauge Chepino line, which threads its way up the Elidere gorge from the Maritsa lowland near Pazarjik to the Chepino basin, in the Rodopi, has been extended across difficult mountain terrain to the upper Mesta valley, where it is making for the fertile basin of Razlog and is intended to continue down the Mesta valley to Nevrokop and across the mountains to the Struma valley. This line serves the richest forest area of the country and has rendered the hot-springs of Chepino and Lajane accessible to tourists. The Struma valley narrow-gauge line is being converted to standard gauge; the existence of this break of gauge half-way down the valley, and the gap in the line at the Greek frontier, are certainly obstacles to the free movement of military traffic down the valley at the present time.

An important link of recent construction runs from Mihailovo, on the Parallel line to Rakovski, on the Orient line. This gives direct access to the Orient line from northern Bulgaria without the long detour *via* Plovdiv; when the train-ferry across the Danube from Giurgiu to Ruse is completed (as it would be by this time but for delays on the Romanian side due to flood damage in 1940) Bucureşti will have a new direct link with İstanbul which will replace the circuitous all-rail route *via* Beograd or the rail-steamer route *via* Constanţa. Lastly, Sofiya, like so many other great cities, has developed a girdle or "ceinture" line to link up industrial establishments which have been springing up in recent years round the outskirts and to avoid the necessity and inconvenience of goods traffic passing through the main passenger station.

*Certain technical considerations*

It has already been shown that the rail traffic of the Balkan Peninsula, both passenger and freight, is of slight dimensions as compared with that of Britain. This is of course primarily due to the fundamental difference in geographical circumstances between Britain and the Balkan countries, and to the absence of large coalfields and agglomerations of industrial population in the

Peninsula. Even if the demand were present however the Balkan railways in their present condition would be incapable of coping with it, by reason of the very high proportion of single-track mileage. Apart from the Beograd–Novska section of the main Simplon–Orient route and the section of the Vienna–Trieste line through the north-west corner of Yugoslavia, there is practically no double-track railway in the whole Peninsula, and multiple tracks such as are so common in parts of Britain are quite unknown. Now the capacity of a railway line to accommodate trains varies so widely with the circumstances of the traffic that it is difficult to generalize, for much depends on the type of traffic, whether passenger or heavy freight, on the possible speed (a function obviously of gradient and curvature of track), on the frequency of passing loops on single-track lines, and on terminal facilities. However as a general average it may be said that between twelve and twenty trains a day each way represents the capacity of single lines such as those of the area under discussion, whilst seventy-two trains a day each way is a figure applicable to double-track lines. The discrepancy between these two figures is obviously of considerable military significance.

The character of the permanent way also has an effect on the handling of traffic. Of prime importance are the weight per unit length of the rails laid, and the strength of the bridges and viaducts, but such matters as the method of tying the rails to the sleepers, the distance apart of the sleepers, and the nature of the ballast which forms the road-bed are also of significance. The influence of permanent way is twofold: in the first place it affects speed, though in the Balkans speed is as often forced to be low by reason of gradients and curves as because of the flimsiness of the track. Thus in Bulgaria for example only 27 per cent. of the total mileage is on a horizontal plane, and 44 per cent. is on gradients steeper than 1: 200 (*cf.* Yugoslavia 40 per cent. horizontal, Switzerland 26 per cent. horizontal), and despite the capacity of the locomotive stock speeds greater than 40 miles per hour are rare, and averages for long "express" journeys (including intermediate stops) are round about 25 m.p.h. Secondly, the permanent way affects the permissible maximum axle load, which in its turn is reflected in the details of locomotive and rolling stock design and in the degree of inter-availability of the engines and vehicles over the various sections of the system. Over much of the standard-gauge mileage in the Balkans the maximum axle load, because of the light-weight rails and other features of the permanent way, is 14 tons, which compares with the British standard for main lines of 22 tons (Germany 20 tons, France 18–20 tons). On the main Orient lines, the Brod–Beograd–Niš section and the Djevdjelija–Piraeus section permit 18 tons, and the Caribrod–Plovdiv section 17 tons, but the Niš–Caribrod section, the Niš–Djevdjelija section, and the line eastwards from Plovdiv only allow 14 tons, and as a result special 56-ton (4-axle) wagons-lits cars have to be employed on the Orient expresses, which are smaller than the standard for western European lines. On many of the local lines in the former Hungarian lands the maximum is 12 or even as low as 10 tons.

Locomotives, owing to the gradients, have to be of large dimensions, and hence in order to get over the axle-load difficulty they have to be built with more coupled wheels than is the custom in western Europe. Thus the

2–10–0 wheel arrangement is a standard for the passenger traffic of the Hellenic State Railways main line and for certain parts of the Bulgarian lines, and the small diameter of the driving wheels gives the machines the appearance of freight locomotives; 10-coupled engines are widely employed for freight traffic also. Elsewhere 8-coupled "express" engines are the rule, and the very fine Yugoslavian Pacifics (4–6–2), built for the more easily graded Sava valley main line, cannot work east or south of Niš. For working heavy coal trains between Pernik and Sofiya, and for the difficult trans-Balkan line, the Bulgarian State Railways have acquired some gigantic 2–12–4 tank engines.

*The Bulgarian State Railways and their traffic*

The study and cartographic representation of railway traffic is a fascinating branch of economic geography, but it is seldom, in countries with a railway network as complex as that of Britain, that sufficiently detailed statistical data are available for any such studies to be made. In those countries however which have a simpler system and a smaller traffic it is common to find that the annual statistical report contains a vast amount of interesting detail, and that of the Bulgarian State Railways' administration is a particularly good example.

The following are intended as a few samples of the kind of analysis that a geographer can make of railway statistics in order to throw more light on the complex relationship between man and his natural and created environment. The figures throughout are those for 1933–34.

*Passenger and freight trains.*—The average number of passenger and freight trains per day running over the various sections of the State railways demonstrate several significant points. Twelve or thirteen trains a day is the maximum density of passenger traffic on any section; the most used lines are the Orient line from Sofiya to Plovdiv, the Sofiya–Varna line between the capital and Mezdra, the junction of the line leading to the Danube ports of Lom and Vidin, the important section between Sofiya and the coal-mining centre of Pernik, the short suburban line from Sofiya to the residential spa of Bankya, and the few miles west of Varna which carries trains for the Ruse line and two branches.

Many of the lines have apparently no goods traffic at all; the explanation of this is that freight and passengers are conveyed by slow "mixed" trains, and even one such train a day was sufficient in 1934 for the needs of the two new branches from Plovdiv to Panagyurishte and Karlovo. How such lines can hope to compete with the growth of road transport is something of a problem, and if the lines did not belong to the State system it is probable that they would not survive. The greatest freight traffic, as might be expected, moves between the Pernik coal-mine and Sofiya. The comparatively small freight traffic passing over the Orient line, especially east of Plovdiv, points to the main function of this line as an international passenger and mail route.

*Relation of railways to industry.*—The sketch-map facing p. 285 shows the location of every factory in Bulgaria which has physical connection with the railway (*i.e.* a siding). The task of making such a map for Britain can well be imagined, and this map serves to emphasize the essential economy of

Bulgaria as a peasant agricultural country. The only important manufacturing industry which is omitted from the map is the textile trade, located mainly at Gabrovo and Sliven; dealing in non-bulky raw materials and housed mainly in small factories and workshops or in domestic dwellings, these trades have no need for railway sidings to serve them.

*Total freight traffic, by stations.*—The overwhelming importance of coal traffic is emphasized on the sketch-map by the figures for Pernik and partly by the high proportion of the traffic of individual stations recorded as "inwards." The growing industrial fringe of Sofiya (*e.g.* large flour mills at Poduene, sugar factory at Serdika) is shown, also the effect of factory industries at Plovdiv and Gorna-Orehovitsa, and the importance of the Black Sea ports of Varna and Burgas and the Danube port of Ruse.

*Cereal traffic.*—Four-fifths of the population of Bulgaria are directly dependent on agriculture for their livelihood, and between two-thirds and three-quarters of the agricultural land is devoted to cereals, which thus loom largely in the economy of the country.[1] The amount of wheat exported from Burgas and Varna has seriously declined within the last few decades, but the trade is by no means extinct and large quantities go by rail to these ports and to the great urban market of Sofiya and other milling centres. A map (not reproduced) showing wheat traffic reflects the distribution of wheat cultivation, which is densest in the drier east; maize is better grown in the slightly wetter north-west, where too the loess soils which cover the limestones of the Danubian Foreland are more retentive of moisture. The sketch-map also shows the total cereal traffic, and is an interesting example of the precise delimitation of a hinterland. The relation of the railway lines to the agricultural areas, to the ports and to Sofiya confines within fairly narrow limits the areas tributary to Burgas, Varna, and Sofiya. Burgas is obviously served only by the south-eastern part of the country, but the northern foreland is divided between Sofiya and Varna, with the two hinterlands overlapping in the area between Cherven-breg and Yasen, where the direction in which the grain goes may depend upon the prices obtainable from the Varna export merchants and the Sofiya millers.

*Traffic on the narrow-gauge lines (map not reproduced).*—The most important of these lines is that which follows the Struma valley. Coal from Bobov-dol and Orlovets and timber from the western flanks of the Rila mountains, served by a branch which in addition carries a small tourist traffic to and from the famous Rila Monastery, form three-quarters of the traffic tonnage. The Chepino line serves the valuable forest lands in the Rodopi; the Orehovo line carries mainly grain, the Kaspichan–Kraina line wood fuel from the Deliorman ("wild forest") region, the trees in this "forest" being stunted and unfit for other use; the Burgas–Pomorie line serves the salt-pans on the northern shores of Burgas Bay.

*Seasonal traffic.*—The detail of the statistics is such that it is possible to discover how much of various commodities is carried by rail in each month of the year, and the graphed figures (not reproduced) bring to light some interesting facts. The total freight traffic is noticeably concentrated on the

[1] See S. H. Beaver, "Bulgaria: a summary." *Geography*, 1940, pp. 159–69; reference on p. 162.

autumn months, with a pronounced peak in October, when harvested crops and winter fuel stores bulk largely in the total, and a minimum in January and February, the midwinter months, when agricultural and building activities are reduced almost to a standstill. The traffic in building materials (bricks and tiles) and in constructional timber are almost identical in their incidence through the months of the year, and are clearly related to climatic conditions and agricultural activities, being lowest in the three midwinter months when temperatures are below freezing for long periods, whilst there is a slight lull in July and August when harvesting is at its height and there is less labour available for building. The peak of the wheat traffic comes in the autumn, soon after the harvest, when the grain goes to the ports and milling centres. The maize traffic reaches its peak much later, at the end of the winter, when the demand rises, for human and animal consumption and for poultry, as the small grains are exhausted. Sugar beet traffic, as in Britain for example, is entirely concentrated on the autumn months (September to November inclusive) when the crop is lifted. Coal and wood fuel show similar traffic graphs; production of both is at its highest in midsummer, and the traffic on the Struma valley, Kaspichan–Kraina and Rakovski–Maritsa narrow-gauge lines shows a marked peak in June and July, but on the system as a whole the peak is in the late autumn when the fuels are moving to the consuming centres for winter storage.

## DISCUSSION

Before the paper the PRESIDENT (Field-Marshal Sir PHILIP CHETWODE) said: I have pleasure in introducing Mr. S. H. Beaver, who is to lecture to us on Railways of the Balkan Peninsula, a part of the world much in our minds at the present moment. Mr. Beaver is a member of the staff of the London School of Economics, who has travelled much in the Balkans, and has special knowledge of Bulgaria.

*Mr. Beaver then read the paper printed above.*

Captain DE TSCHARNER (War Office): I should like to express appreciation of the most interesting lecture. I am glad to have had the opportunity of hearing Mr. Beaver.

The PRESIDENT: The interest of the lecture to us has been not only in the technical part, but also in looking at photographs of a country which may be at any moment used by the Germans if they choose to attack Greece. I ask you now to thank the lecturer for what to many of us has been an extraordinarily interesting lecture.

*The lecture was illustrated with diagrammatic maps, many of which could not be reproduced. They are preserved in the Map Room of the Society and can be consulted by students.*

# THE STRUCTURE OF A TEMPERATE GLACIER

## A résumé of the glaciological research made by Dr. T. P. Hughes, Dr. Max Perutz, and the author at the Jungfraujoch

*Publication No. 4 of the Jungfraujoch Research Party, 1938*

GERALD SELIGMAN

*Meeting of the Society, 10 March 1941*

WISHING in the autumn of 1936 to resume work on the transition of snow into denser forms, I considered, on the suggestion of a friend recently in the Arctic, how to bring Polar conditions to convenient laboratories, and thought of a station in the Alps. The late Professor Schmidt of Vienna, proposed the Sonnblick Hut in Tirol, but I decided on the Jungfraujoch, where living is expensive but the railway leads to the door of the laboratory. In the late summer of 1937 I studied the conditions there with Dr. P. Bowden of the Physical Chemistry Laboratory, Cambridge, Professor J. D. Bernal, Dr. H. Bader of the Swiss Snow and Avalanche Commission, Dr. T. P. Hughes of Caius College, Cambridge, and Dr. Max Perutz.

The work of earlier investigators and my own had traced the transition of new powdery snow into hard firn snow, but no one had systematically studied how this white, air-filled firn turned into the blue air-free ice of the lower glaciers. This was the ground of the present research. Glacier movement had been supposed to play a part, and this had to be investigated, including of course the flow of the *névé*. My long-cherished desire to use polarized light to reveal the detailed development of firn and ice crystals required the help of a crystallographer, which led to unexpected and valuable results. With the exception of a few desultory photographs polarized light had never been used: a surprising omission in glaciological research.

As practically nothing was known of *névé* temperature in Alpine glaciers, this had to be studied, with the allied question of the amount and mode of flow of melt-water in the *névé*. We proposed to examine also whether the bands of pure ice that develop in the air-filled firn, high up in the *névé* areas, were the same as the blue bands of the lower glacier, a subject of age-long controversy; it was also necessary to measure the settlement of snow and firn in the *névé* areas, and the resulting increase of specific gravity. All this bore upon our main problem, the change of firn into glacier ice. An investigation of the friction between ice and other solids had long interested our senior physicist, and he wished to complete his work in the field as a side issue. Most glacier studies had begun at the glacier tongue, and if they worked up the glacier at all they had seldom proceeded to the top. It had always seemed necessary to me to start at the beginning, the glacier source, first investigating the raw material, the falling snow lying upon the older firn, and then tracing its history in correct chronological sequence as it became firn and then ice.

To meet part of the heavy expenditure the Leverhulme Trustees granted me a Research Fellowship; the Royal Geographical Society and the Alpine

Ski Club made grants; the Ski Club of Great Britain bore part of the cost of our ski equipment; the London Chairman of the Swiss Federal Railways gave free passes and transport on their lines; and the Chairman of the Wengern Alp and Jungfrau Railways gave the whole party free passes which allowed us to return to lower levels for work and rest. Many British firms gave us supplies or instruments either free or at reduced prices. For all this help we are greatly obliged.

Much advice and preliminary help had been given by Professor Ahlmann, of Stockholm. Dr. Bowden has given me continual assistance, not only in recommending my staff but in every other possible way. Dr. T. P. Hughes, now Fellow of Caius College, Cambridge, came as physicist; Dr. Max Perutz, then of the Cavendish Laboratory, as crystallographer; Dr. A. E. Benfield, then of the Department of Geodesy and Geophysics, Cambridge, did the preliminary physical work until relieved by Dr. Hughes; and Mr. E. A. Ferguson, of the Cambridge Geographical School, was general assistant.

Professor E. Niggli of Zürich, allowed us to see the work of the Swiss Snow and Avalanche Research Station at the Weissfluhjoch under the guidance of Dr. H. Bader and Dr. R. Haefeli, who instructed our crystallographer in their section-cutting technique and visited us at the Jungfraujoch to give us the benefit of their advice on many matters. Professor A. von Muralt, Chairman of the executive committee of the International Research Institute at the Jungfraujoch, gave us much assistance, and we are indebted to him for many courtesies. Finally my old friend and guide, Fritz Steuri, gave us invaluable advice and assistance in all field work.

The Jungfrau railway, approaching from the direction of the Mönch, ends in a large hall excavated from the rocky eminence, the Sphinx (see Plate 1), which is pierced by tunnels connecting the hotel and restaurant, the quarters for tourists and railway staff, the elevator to the meteorological station on the summit, and the astronomical and research institutes.

The Joch proper, or saddle, is the level stretch at 3460 metres on the left of the plate. This descends sheer to the north-north-west in enormous ice-falls and precipices to the inhabited valleys of the Bernese Oberland. To the west rises the north-east ridge of the Jungfrau, commencing with the sentinel, the Matthildenspitze, and to the east the ice-ridge of the Sphinx. In this steep apron of ice we excavated our cold laboratory.

Ice apron is the name, suggested by Mr. N. E. Odell, which we have given to the ice formed by the freezing of melt-water which runs down over the rocks of high mountain peaks and ridges. Except for a slight "creep," which we were able to measure, this ice is stationary. At the lower end of the ice apron is the bergschrund below which the glacier proper begins.

From the saddle and the cirque formed by the Jungfrau the Great Aletsch Glacier commences its 17-mile journey to the Rhone Valley, its upper reaches at this point being called the Jungfraufirn. It is soon joined by the vast Mönchfirn which starts at the Obermönchjoch beneath the slopes of the Mönch beyond the top right-hand corner of Fig. 1. Access to the Mönchfirn is made easy by a tunnel cut from end to end of the Sphinx rock debouching on to the almost level *névé*. It was here that we decided to carry out most

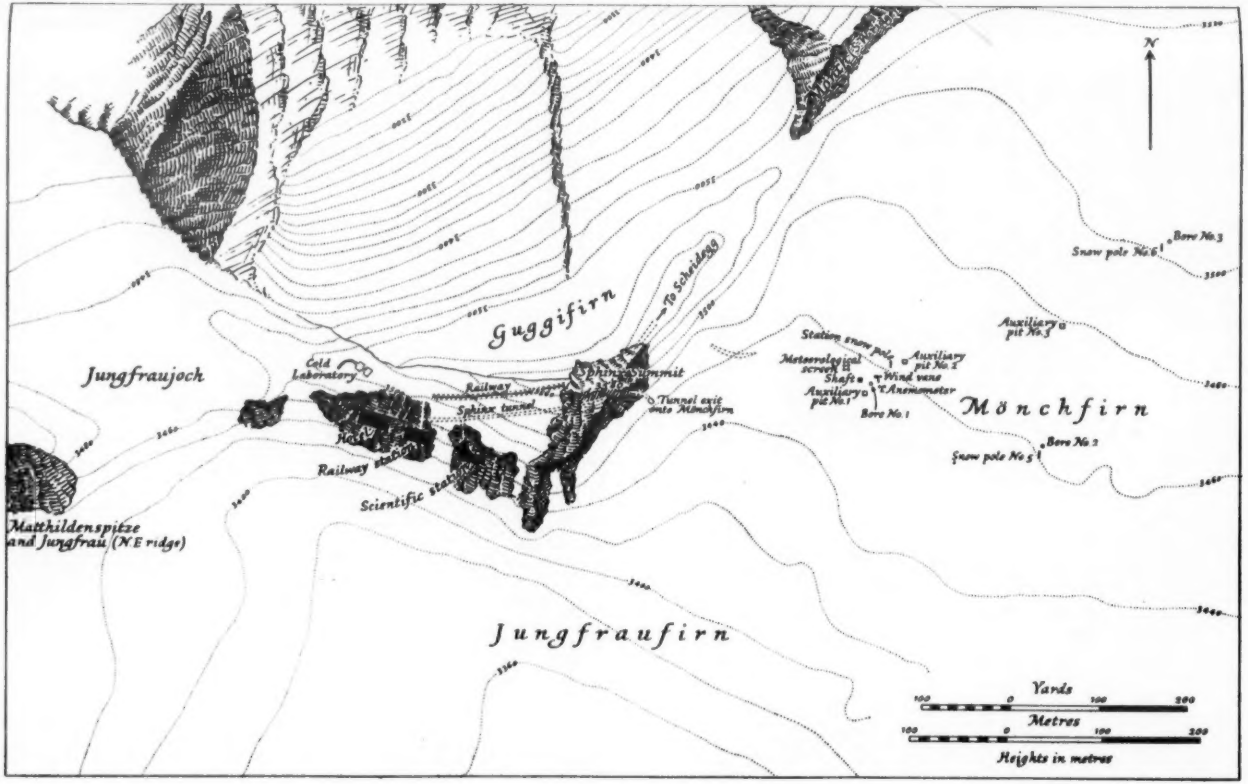

N
Guggifirn
To Scheidegg
Jungfraujoch
Cold Laboratory
Railway
Sphinx tunnel
Tunnel exit into Mönchfirn
Railway station
Scientific station
Matthildenspitze and Jungfrau (NE ridge)
Jungfraufirn
Mönchfirn
Station snow pole
Meteorological screen
Shaft
Auxiliary pit No. 1
Auxiliary pit No. 2
Wind vane
Anemometer
Auxiliary pit No. 3
Bore No. 1
Bore No. 2
Bore No. 3
Snow pole No. 5
Snow pole No. 6
Yards
Metres
Heights in metres

*Fig. 1*

of our investigations, partly for convenience of access and partly because the steady flow of the *névé* at this point promised that our excavations and work generally would not be interrupted. The various observation points which we made there are shown in Fig. 1.

Several papers on the results of the Jungfraujoch Research Party 1938 have already been published:

Publication No. 1 is 'A crystallographic investigation of glacier structure and the mechanism of glacier flow,' by M. F. Perutz and Gerald Seligman. Proceedings of the Royal Society, 23 August 1939. Series A, vol. 172, pp. 335–360.

Publication No. 2 is 'The temperature, melt water movement, and density increase in the *névé* of an Alpine glacier,' by T. P. Hughes and Gerald Seligman. Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, 1939, December, vol. 4, pp. 615–647.

Publication No. 3 is 'The bearing of snow permeability and retentivity on the density increase of firn and ice-band formation in glaciers,' by T. P. Hughes and Gerald Seligman. Bulletin of the International Association of Scientific Hydrology; *in the press*.

The present paper deals with the Programme, Instruments, and Methods of the whole research, and summarizes the results of the above publications.

*The cold laboratory.*—In September 1937 we had found the temperature in a shallow ice-grotto to be −4° C. During the winter I designed a laboratory with a 16-metre tunnel approach, straight into the ice-apron below the Sphinx ridge, and entrusted the excavation to Fritz Steuri, who found and used an old tunnel approach to an artificial cavern formerly used to entertain tourists and to store food (Fig. 2). This saved much labour. The tunnel had a fall outwards to carry off melt-water into a drainage channel, of which the upper section was boarded to keep it clear of snow. Two loose boards marked by a stake made a convenient entrance easily cleared of snow after a blizzard, snow accumulation being very limited so close to the wind-swept Joch.

Two doors, one at the entrance and one at the laboratory, were kept closed to prevent convection, and to stop the heavy cold air running downhill from the laboratory. At the first serious thaw of the season melt-water came through two clefts in the roof, which we blocked with rubbish, then with wet snow, and sprayed with water in the evening. This froze solid and we were never troubled again. On August 2, during a very heavy thaw, I noted: "Laboratory bone dry." On our arrival in April the laboratory temperature was −3°5; it was −4°2 on June 7, −3°7 on June 30 with heavy thaw outside, −3°5 on July 5, and −4°0 on August 2. With one man working alone it might rise a degree by the evening; two or three working together, or a party of visitors might raise it perilously close to zero. We found on arrival exquisite crystals of crevasse hoar in the tunnel, some being 8 inches long with scrolled sides. During our work they did not increase in size, but became coated with a fine dust of secondary hoar, confirming my belief that large crystals grow only in undisturbed air holding little water-vapour.

Phot. A. Klopfenstein

1. *Jungfraujoch, Mönch, and Sphinx: Note*

Phot. A. Gyger

2. *Ice-apron on north wall of Sphinx: Note*

Phot. H. Bal

*3. Mönchfirn from summit of Jungfrau*

| | | |
|---|---|---|
| *South-eastern point of Sphinx* | 0·5 | 2·0 |
| *Jungfraufirn* | 1·3 | 1·2 |
| *Obermönchjoch* | 0·9 | 3·8 |
| *Crevasse H* | 2·2 | 2·5 |
| *Crevasse V* | 4·8 | 1·9 |

| | | |
|---|---|---|
| *Firn research mainly carried out* | 0·8 | 2·3 |
| *Beacons for measuring speed of glacier* | 1·5 | 2·7 |
| | 1·8 | 2·7 |
| | 2·1 | 2·8 |

*Coordinates in inches from left and lower edge*

The laboratory benches were simply unhewn ice covered with boards. Light and power were brought by mains from the railway. Work in the cold laboratory was not unpleasant; on a snowy day it was a relief to escape from the wind. Perutz, who worked there longer than others, wore an old airman's suit, and put his feet in sacks stuffed with straw. Hughes seemed to thrive on cold.

*The shaft.*—Poor success in preliminary borings decided us to sink a shaft to 20 metres and 2 by 1 metres in section with horizontal boring holes 3 metres long to take thermocouples. Professor Ahlmann had advised these horizontal

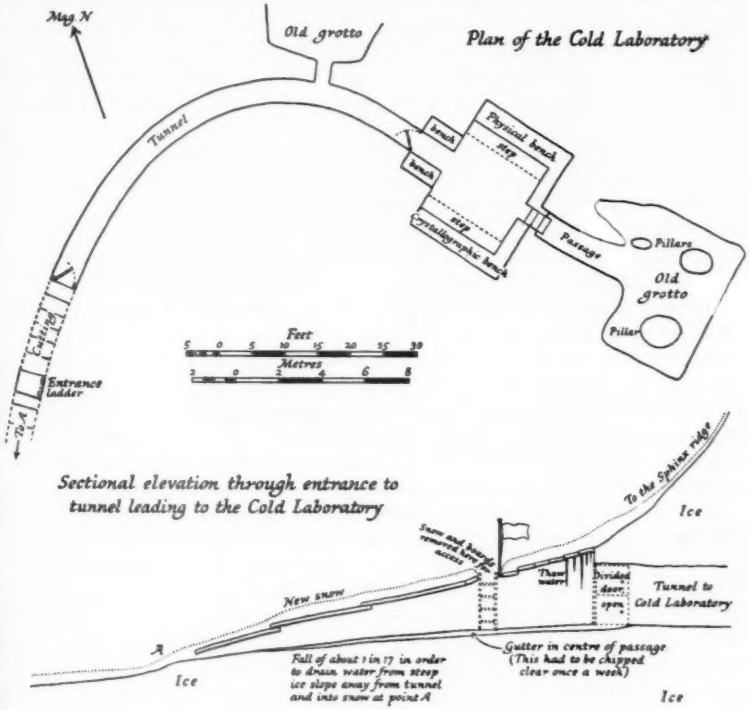



*Fig. 2*

borings to escape the influence of the main shaft on firn temperature. We had proposed to bring up samples of firn for crystal analysis from crevasses, but in May found them so full of snow that the shaft was better for this purpose also. The shaft was begun at noon on May 6 and excavated by hand for 3 metres in a few hours. On May 9 we erected a $2^1/_2$ h.p. winding engine, and F. Steuri, with a young assistant, P. Egger, took charge of the excavation and reached over 20 metres by Saturday May 14 in forty-two working hours, with two men on the bank to clear away the debris, and one engine man.

At first they dug with a long-handled shovel, changing to a heavy adze and a pick, curved and sharp pointed, as they came to denser material. At 20

metres the specific gravity of the firn had increased from 0·4 to 0·7. We could not keep the shaft open, as our principal object was to take temperatures, so we bored another 10 metres vertically and 3 metres horizontally from the 20-metre bottom to take the lowest thermocouples.

I believe that with time and improved gear it would be possible to sink to much greater depths. It might be necessary to strengthen the pit bank, but the shaft walls would I think hold firm with little or no support if the work could be finished before the glacier moved much. Some day shafts must be taken right down to the glacier bed, and until this is done many problems of the upper *névés* will remain unsolved. The problem, although formidable, is not insuperable, especially as I think it will be found that at this altitude the *névé* is of no great thickness. We thought it might reach 100 metres *in the centre* of the Mönch firn, and at the point where our shaft was it would be much less.

Twice each day during the excavation Ferguson and I went down and took measurements of specific gravities and collected samples for crystal analysis which were carried in wide-necked Dewar flasks to the laboratory to await the arrival from England of Dr. Perutz.

Standardized thermocouples, two for each level, were attached with their leads at suitable intervals to an old rope, wound on an improvised felt-covered drum, and lowered in a niche about 30 by 15 centimetres in a corner of the shaft, to avoid damage during re-filling. The drum, carrying the upper ends of all the leads, was fixed to a couple of posts 2 metres high. We then filled in the shaft to 15 metres, having fortunately plenty of new dry snow; we next bored two holes horizontally 3 metres for the next pair of couples; did the same at 9 metres; and by May 21, after a fortnight's work for three men, the shaft was filled to the surface. We had meant to block the thermocouples into their bores with cold snow, but substituted frequent wads of cotton wool.

*Boring tools.*—I had received from Mr. N. E. Odell a set of rods to Ahlmann's design, each metre rod weighing nearly a kilogram, with a spoon 38×3·8 centimetres. From Messrs. C. Isler and Co., of Southwark, I obtained another set, each 91·5 centimetres long and weighing 1·13 kilogrammes. Neither set was quite strong enough, even for boring to 10 metres. They tended to snap at the end of the thread, and the threads to strip; the adapters and muffs should be sweated, or better, welded on. Messrs. Isler took much trouble in making the set to my specifications; they have examined the rods which failed and will now, I am sure, be able to make just what is wanted.

Early experiments in March 1938 were disappointing; we happened on a patch of solid ice with tools intended for firn. I then ordered two Irwin augers, to my own design: one, with an enormous leading screw and powerful cutting cheeks, worked admirably in blue ice. A spoon was used to remove the chips; this was carried on a second set of rods to save the time of changing. Fortunately however the difficulties we had experienced in March did not recur.

At the bottom of the 20-metre shaft Benfield began boring horizontally with this auger, but when he came to clear out the chips with Ahlmann's spoon he continued to bore with it, and reached 3·1 metres in less than an

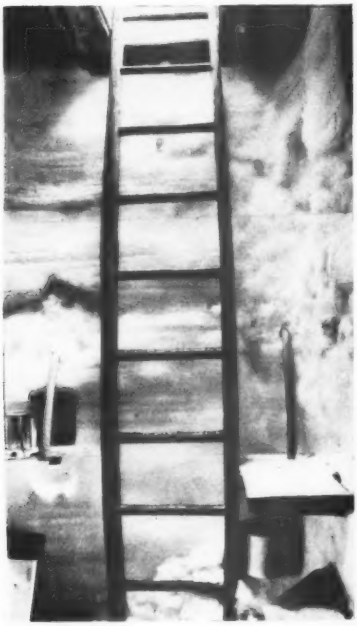
*4. Ferguson and Benfield at the shaft*

*5. Entrance to auxiliary pit No. 2*

*6. Lowering thermocouples into shaft*

*7. Wooden clamp for boring rods*

*8. Shaft: ladder and safety platform*



*9. Auxiliary pit No. 2: pipes from melt-water pans*

hour. He then bored downwards vertically 6 metres in two hours, and another 3 in two hours more; as the line of rods grows there is naturally more labour in unscrewing them each time the spoon has to be cleared. At this time the temperature of the firn was 0° C. and the coherence of the grains reduced; but later we found no special difficulty at −8° C.

It is important to keep the inside of the spoon free from rust and well greased, or the chips stick, and the cutting edge razor sharp. It would pay to have the spoon of stainless steel or chromium plated. Up to 10 metres we did not use a derrick for drawing the rods, but should have been glad of one at 6 metres. Low melting-point grease and graphite kept the threads from sticking.

For bringing up undamaged cores I had a special spoon-shaped head made with different crowns. A promising pattern had twelve teeth, eight pointing inwards to hold the core, and four outwards to do most of the cutting. This head brought up samples from below the shaft bottom and they seemed quite undamaged. I tested straight and S-shaped percussion tools, but found them useless in our conditions; they might work at very low temperatures.

*Auxiliary pits.*—No. 1 was dug for measuring temperatures. No. 2 was made on June 15 for observing the shrinkage or settling of snow and firn, melt-water percolation through the firn, and ice-band formation. It was first $2\frac{1}{2}$ metres deep by $2 \times 1$, but was often altered. Its top was boarded, with an entrance made of a packing case with a hinged lid, like that used by Glen in North-east Land; a fixed ladder gave ingress. Only once was the entrance seriously snowed up. I spent much time in this hole, relieved to escape from the wind and snow outside, and to work in the comparatively comfortable temperature of freezing-point. No. 3 pit was dug on August 11, like No. 2, but with a plain board cover, near the foot of a steep incline on the glacier surface.

*Crevasses.*—I believe the great depths attributed to crevasses in the Alps are mythical. We explored many, and the greatest depth we reached was 30 metres; a crevasse said to be at least 60 metres deep proved no more than 25. Sun never reaches the bottom of crevasses, so that snow remains like flour if no melt-water can run in, and anything dropped to the bottom often sinks deep; even large objects may never be found again. This probably accounts for the not infrequent complete disappearance of the victims of accidents.

For descending we had four rope ladders of 15 metres each, fastening together with spring clips. Two metres of ladder were laid on the snow, two stout posts were driven in on the crevasse side of a rung about 1 metre from the edge and a third post below the upper rung. This held well even in comparatively light firn snow; in winter longer posts and more ladder on the surface would be better. A man descending was always secured by a rope, with a useful belay which could be very quickly undone. A thin rope sling round the body, with a spring clip to the ladder, left both hands free for work. The middle and bottom of the ladder were, when possible, secured with hollow ring-spikes, which are particularly useful in firn, and much better than the old solid spikes. As a rule I had two men at the top, one to watch the operator and take notes and instructions, the other to handle the rope. A

small bag was used to let down supplies and bring up samples; large tools like the heavy ice-pick were always sent down *before* the operator.

*Samples from crevasse walls.*—The surfaces are generally weathered to 1 foot or more by melt-water running over the face. The weathered portion was removed with the heavy ice-pick, of which every glaciological expedition should have several, kept extremely sharp. A large square block is hewn, and its orientation in the glacier marked by a saw cut. On the surface it is trimmed and immediately placed in a Dewar flask cooled with solid carbon dioxide, which must always be carried to the laboratory on the same day. A chisel, mallet, and one or two small saws completed the outfit.

*Specific gravity.*—For loose snow we adopted Dr. Bader's bright-machined steel cylinders with a chisel-like cutting edge, and added Dr. Eugster's device of a transverse slot through which a steel plate can be introduced, the volume between the cutting edge and the slot being 500 cubic centimetres. At the rear end beyond the slot is a cross cut into which the steel plate can be inserted, by which the cylinder is gently twisted horizontally into a vertical section of the snow. The shell is then dug out, the plate introduced into the transverse slot, and all the snow behind it allowed to fall out.

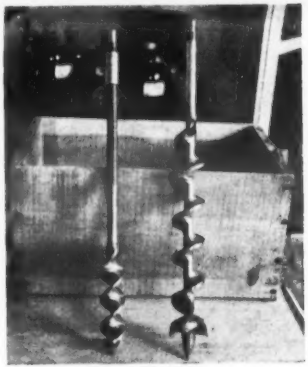
For compacted snow we used a more robust shell, with a saw edge of very large teeth, and two transverse slots at a distance apart to give 500 cubic centimetres, of which one is near the teeth and the second near the base; this shell has holes for a tommy-bar by which it is pressed in with the same rotary or reciprocating motion, which must not stop or the core tends to crack. These shells must be clean and well greased; they would be better of stainless steel or chromium plated. In the field snow was weighed in its shell; firn was turned out into the pan.

For very hard firn this may not work; it must then be cut into cubes by saws with alternate teeth set to one side, the others left unset so as not to scratch the steel square. To get accuracy of $\pm 0{\cdot}005$ in the result requires great skill and many precautions, especially at higher temperatures, when the saw may drag off the grains.

When this method was not suitable Dr. Perutz devised the following: a small block was weighed, immersed in heavy machine oil, wiped with gauze after the oil had displaced all the contained air in the communicating pores, and placed in a flask, which was weighed, filled up to a mark with trichlorethylene, and weighed again. From the three weighings the specific gravity of the sample, and the respective volumes of communicating and non-communicating air could be calculated. The results obtained by the shell and the oil method showed good agreement, and the densities should not have errors of more than about $\pm 0{\cdot}005$.

*Crystallographic examination.*—To cut thin sections a cube of about 1·5 centimetres was cooled with solid carbon dioxide and one face ground flat on glass paper and polishing paper. On regaining room temperature it was frozen to a microscope slide clamped on the stage of an ice-microtome, designed by E. Schiltknecht, of Zürich, and lent us by the Swiss Snow and Avalanche Commission. The machine and its use are fully described by Bader.

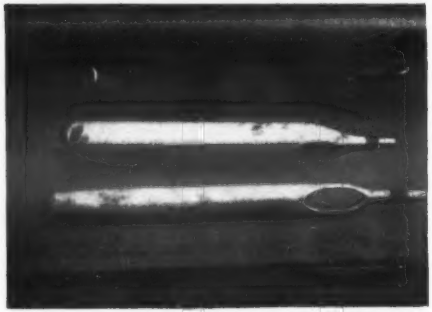
Sections larger than 4 centimetres across, to show large crystals, had to be



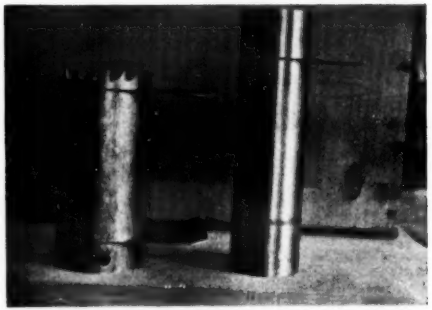
*10. Ice drills: Note*

Phot. H. Steuri

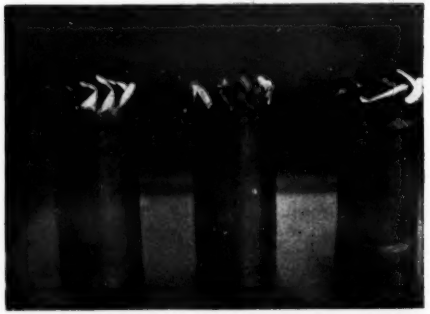
*11. Fritz Steuri with heavy ice-pick*



*12. Spoons: Note*



*13. Specific-gravity shells: Note*



*14. Coring heads: Note*

*15. Re-inserting rods in bore*

*16. Snow bridge 22 m. below surface. Crevasse II*

ground by hand on glass paper, cooling for half an hour after each minute's grinding. Sections 5 centimetres across and 0·1 thick were made, but tended to crack very easily by thermal tension. This process was extremely laborious.

The sections were examined in a specially built polarizing enlarger with which many photomicrographs were made. Crystal orientation was measured on a polarizing microscope lent by Professor Tilley of the Department of Mineralogy, Cambridge. The methods and results are described in the paper by Perutz and Seligman, Proc. R. S., 172 (1939) 335–60 (Publ. No. 1).

*Temperature measurements.*—Profiting by the experience of Ahlmann and Sverdrup, we decided to use thermocouples of copper-constantan twin-wound wires calibrated at the Jungfraujoch, and read by an enclosed lamp and scale galvanometer of very robust type, carried about the glacier, and operated under a tent which protected instrument and observer from snow and gave the necessary shade. We mounted the tent on ski, which however did not work well in soft snow. A small tent of dark material mounted on an efficient sleigh runner would have been very valuable.

The methods and results of this work have been published by Hughes and Seligman in *Monthly Notices* R.A.S. Geophysical Supplement, 4 (1939) 616–47 (Publ. No. 2).

*Meteorology.*—By the courtesy of Professor P. L. Mercanton the observations made at the new meteorological station on the Sphinx were available to us daily, and at that exposed position differed from ours on the more sheltered slopes of the glacier. For the period May 7 to August 21 the mean air temperature on the Sphinx was −2°2 C., on the glacier slightly over +1°; the relative humidity 58 per cent. as against 70 per cent., and the mean wind speed 22 km./hr. compared with 10 km./hr. about 1 metre above the glacier.

Our instruments, lent by the British Meteorological Office, were housed in a Stevenson screen bolted to a large packing case, itself lashed to a pole thrust deeply into the snow. This had to be rebedded several times owing to melting of the surface snow. Experiments with a cambric cover to keep snow out of the screen gave promising results, which will be published elsewhere with our studies of snow accumulation and ablation.

For our work at the meteorological station we found it sufficient to wear the clothes of a winter skier with an extra sweater or two and windproof anorak and trousers of Grenfell cloth, arranging our programme so that exposed tasks were done in fine weather. In crevasses water drips continually during summer even at high altitudes, and waterproofs are necessary.

For routine work the racket ski, which I had designed some years ago, were invaluable; they do not get in the way when reading instruments, and a member of the party who could not ski used them at once.

## *FIRNIFICATION*

Firnification is the name applied to the successive changes which occur to fallen snow and which ultimately convert what was originally a fluffy or powdery mass into dense, glassy ice. The appearance of the snow at the various transition stages is illustrated by a series of photographs in my book 'Snow structure and ski fields,' Nos. 91, 92, 99, 109, but the actual changes in the snow-flake, as seen through the microscope, are as follows: we first have

the dendritic snow-flake (121.a) the hairy tendrils of which give the fluffy appearance to very new snow. Gradually these delicate plumes evaporate and the snow becomes more and more granular (121.f), the grains increasing in size as water vapour from the evaporating plumes condenses upon them. The second photomicrograph (121.b) in this series corresponds with this stage, which is usually described as "powder snow." The physical properties of the snow and firn at successive stages are set out in the table below.

| *Sp. G.* | *Grain size* | *Depth* | |
|---|---|---|---|
| 0·291 | 0·1–0·2 mm. | ·16 m. | Settled Snow |
| 0·437 | 0·3–0·5 mm. | 1·10 m. | Early firn |
| 0·463 | 0·6–1·3 mm. | 2·70 m. | Firn |
| 0·690 | 1·0–2·0 mm. | 23·25 m. | Denser firn |

It was at the second stage that our research started, for I was anxious to see by what mechanism the change into glassy ice took place. The earlier stages are well shown in Plate 21, and it will be seen that at this stage the firn grains grow in size and the firn becomes denser.

The first two photomicrographs illustrate clearly how the firn, which is white owing to the many air spaces, turns into glassy ice having few air spaces. These photomicrographs are of thin polished sections of firn and glacier ice less than a single crystal in thickness. They are photographed in polarized light, which enables the individual crystals possessing various orientations of their optical axis to transmit different intensities of illumination, and thus to show up clearly in the photograph. In the first, Plate 24, the firn grains show up white or grey and very angular in outline. Between them are a number of well-rounded black spaces which are channels of air. These are the remains of the air spaces between individual flakes of snow, but the fusion of the snow has not been sufficient to close them and there is thus a ramifying network of air channels throughout the firn mass. This gives it its characteristic white colour, less white than snow, but white nevertheless. The next photograph (Plate 25) shows a diminution in extent of these air channels, the sample having passed over into ice. The air channels have become sealed up and are no longer communicating.

This gives us a convenient definition of both firn and ice. The former is snow which has become granular and compacted and possesses intercommunicating air channels; it is therefore permeable to water. Glacier ice is firn in which the intercommunicating air channels have become sealed up, rendering it impossible for water to pass through. If there is any air present in ice, it is in closed and non-communicating vesicles. We found that the transition from firn into ice took place with remarkable uniformity when the density of the firn was between 0·82 and 0·84.

It is important to note that the ice crystals in the first two photomicrographs are no larger than those of the firn. The third shows very distinctly the difference in the size of the crystals found in glacier tongues, and how markedly larger they are than the small crystals of the newly formed ice. I shall presently explain the reason for this.

Having examined the nature of the transition, we naturally want to know what brings it about. Actually, the change is caused by several agencies. Of

these, the chief are the freezing of melt-water, and the settling of the firn. There is a third factor, the movement of the firn, but, as we shall see, this has a greater importance in bringing about the growth of the grain after the ice has been formed, as exemplified by Plate 26. We now have to consider these two main factors.

*The freezing of melt-water.*—Very little was known about temperatures in temperate *névés* and we had to conduct what I think was the first systematic measurement of *névé* temperatures carried out over an appreciable period in a temperate glacier. Since the rise in temperature of the firn could only be

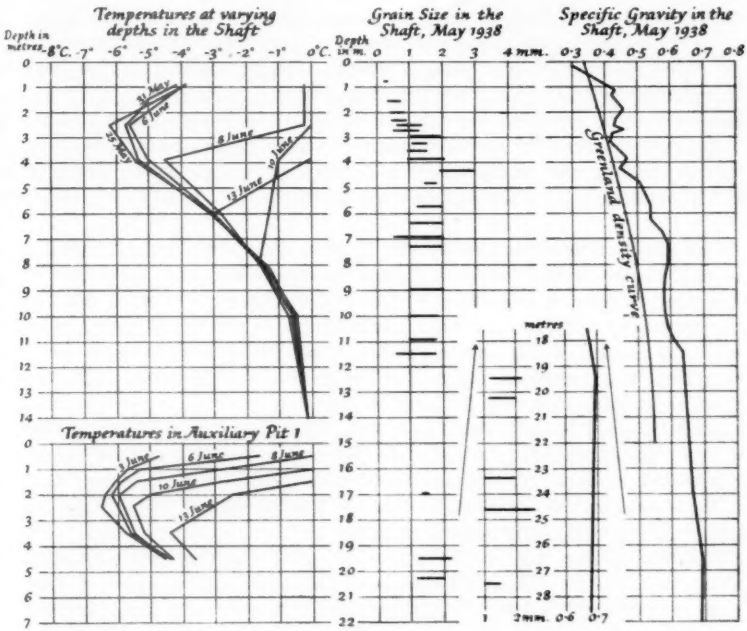



*Fig. 3*

interpreted as the result of a downward penetration of melt-water, direct measurements of the nature and magnitude of melt-water movements in the firn were attempted.

Our temperature measurements, described fully in Publ. No. 2, lasted from the end of May until the middle of August, that is, throughout the Alpine summer. Figure 3 shows that at the beginning the *névé* had a negative temperature down to a depth of about 15 metres. At the surface the temperature was of the order of $-4°$ C. to $-7°$ C., decreasing to a minimum between 3 and 4 metres depth and then rising to zero and reaching it at about 15 metres. This negative temperature is due to the penetration of the winter

cold wave caused by the low mean air temperature throughout the winter, and we have strong evidence that it never penetrated lower than this, and that, at this altitude and latitude, zero temperatures rule below 15 metres throughout the year.

To call this temperature *zero* is not quite accurate, as the ice appeared to be at the pressure melting-point at depths below 15 metres. The difference between this temperature, about −0°·013 C. at 30 metres, was just too small to be measured accurately. As the summer proceeded the temperatures gradually rose until by midsummer the whole of the *névé* area was uniformly at zero.

Fig. 3 shows how, early in the year, the temperature rise of the *névé* is such as can be caused by conduction, but once the active summer heat has started an abrupt rise of the curve shows, as Sverdrup has shown, that another factor is assuming control. This is the percolation of melt-water, which freezes on coming into contact with the colder zones below, releasing latent heat and thus rapidly causing the *névé* temperature to rise. These curves, then, prove that descending melt-water freezes and causes an increase in the density of the firn and assists in closing up the air spaces.

*Melt-water measurements.*—We attempted to make direct measurements of vertical and horizontal flow of melt-water at various depths in the firn. This was done by burying large draining pans, filled with snow to avoid changing the conditions of flow inside them, in the faces of pits 2 and 3 dug in the *névé*; the amount of water flowing into the pans and then draining out into a receptacle was measured daily. The quantities of melt-water percolating down through the firn were found to be very dependent on the weather, that is, on the supply of melt-water from surface melting. During warm weather the flow into a horizontal pan was of the order 0·2 cubic centimetres per square centimetre per hour. Russian scientists, working on the surface of the tongue of the Karaugom Glacier in the Caucasus, obtained figures of 0·19–0·35 cubic centimetre per square centimetre per hour.

Solutions of dyes were used to study the speed of flow of melt-water both along and into the glacier. Welzenbach published some speeds of water movement through firn which show that the larger the grains the greater the speed, other factors being equal.

Our own experiments were carried out in order to ascertain large-scale water movements in the *névé* surface in summer, and took no special account of grain size. In one case fluorescein strewn on the surface 4 metres upstream of No. 2 Auxiliary Pit appeared in the top (upstream) wall of this pit in forty-eight hours, which is equivalent to 8·3 centimetres in an hour. The slope of the glacier and of the strata at this point was 8½°. It is perhaps only a coincidence that Welzenbach found this identical speed for water moving along a water-conducting stratum of slightly less inclination but rather bigger grain size; the approximate grain size in our case was 0·5–1·5 millimetres, in Welzenbach's case 2·0 millimetres.

Despite the movement of these large quantities of melt-water through the firn, calculation showed that the "quantity of cold" available at the end of winter was not sufficient to account for the whole of the observed increase in

Phot. P. Bowden

*17. Hughes and Seligman on racket skis*

*18. Reading the galvanometer*

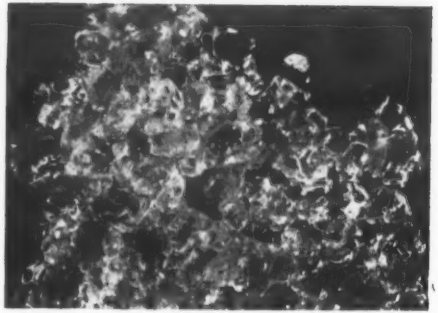
*19. Perutz in cold laboratory*

*20. Hughes in cold laboratory*

*CRUSHED FIRN*

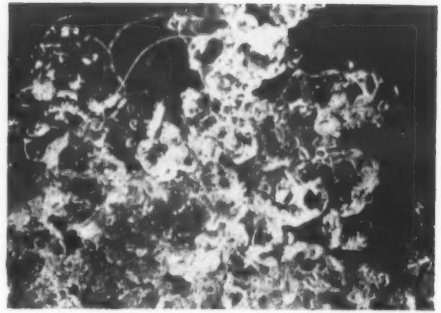
× 6·5

*21. Early at 1·10 m. S.G. 0·44*



× 5·2

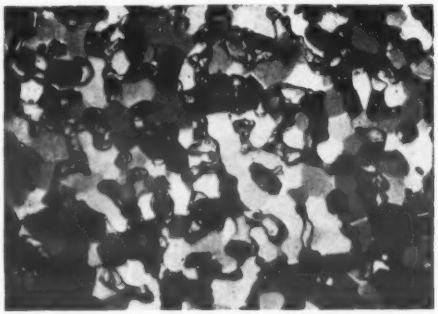
*22. Firn at 7·32 m. S.G. 0·60*



× 5·2

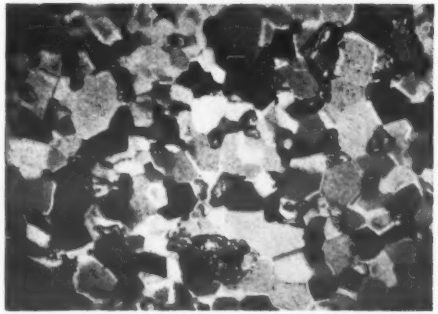
*23. Firn at 30·35 m. S.G. 0·69*

*SECTIONS IN POLARIZED LIGHT*



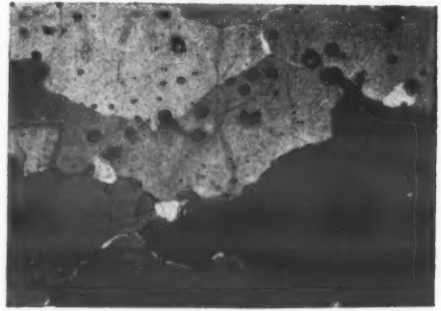
× 4·1

*24. Old firn (3 years) at 14 m. S.G. 0·72*



× 4·1

*25. New ice (6 years) at 23 m. S.G. 0·80*



× 3·5

*26. Serac ice S.G. 0·92*

density during the summer. We therefore had to look for some additional cause.

*Settling of the firn.*—Fortunately we had made careful measurements of the settling of both snow and firn during the summer. This was done by making daily measurements of the distance between a row of wooden pegs or steel pins placed in the walls of the main shaft and Auxiliary Pit No. 2, and by various briefer experiments.

In freshly fallen snow the settling during three days at temperatures just above zero was sufficient to increase the density from 0·15 to 0·36. At a temperature below zero the density increase was less, from 0·15 to 0·25 in three days, due in part to the absence of a lubricating film of melt-water.

In firn the settling rate was measured by pegs and also by a so-called "firn compression meter" similar to that described by Moss. The results showed

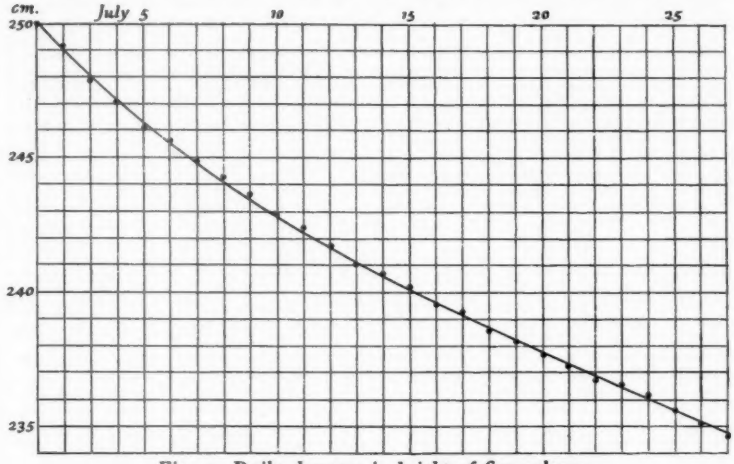



*Fig. 4. Daily decrease in height of firn column*

local variations in rate of settling due to differing firn properties, and a dependence of this rate on the melt-water content of the firn. Generally speaking though, the average results indicated that a regular shrinkage of the firn of about $2{\cdot}3 \times 10^{-3}$ cm./cm./sec. took place throughout the whole of the summer at a depth of 2 metres. This rate was maintained even when the temperature of the firn was below zero. The increase in density resulting from this slow but regular settling corresponded to an increase of from 0·4 to 0·52 in one hundred days, which was in fact of the same order as the density increase at a depth of 1·2 metre during the summer (Fig. 4).

The experiments on glacier movement which are described below show that the consolidation of the firn takes place by the relative slip and rotation of firn crystals and crystal aggregates until a high degree of close packing is achieved. The experiments made on ice-band formation, described more fully elsewhere, suggest that the final blocking of the inter-communicating air spaces is brought about by the freezing out of descending melt-water. This

water cannot drain any deeper and must tend to flow along above the impermeable firn or glacier ice. When the temperature is below zero underneath this layer, the melt-water freezes out and heats up the underlying layers. As has been previously mentioned this change from the permeable to the impermeable firn is not accompanied by a marked rise in either the density or the grain size. The further changes in the density and grain size which take place during the slow transformation of impermeable firn or young glacier ice with a density of about 0·83 into the larger-grained typical ice of the glacier tongue with a density of about 0·92 are the result of the crystal growth, accompanied

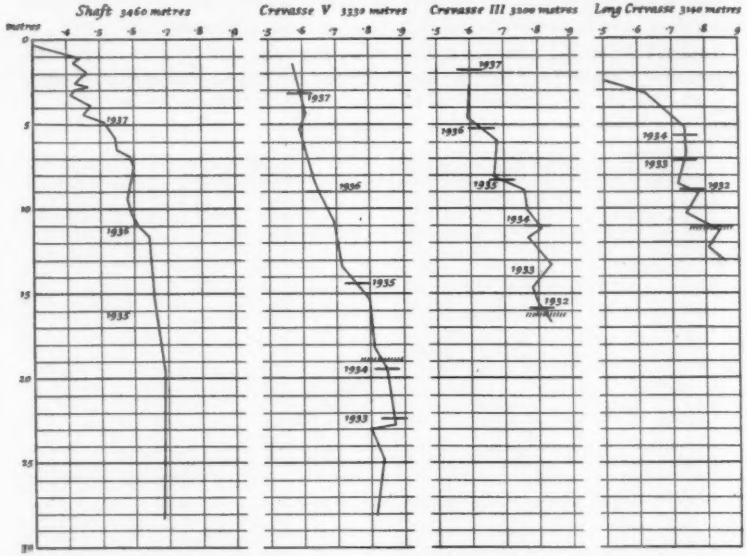



*Fig. 5. Firn densities in the* névé *area. Firn line shows annual bands; hatched line, transitional zone from firn to ice*

by a certain degree of settling and loss of air, which takes place during the continuous plastic deformation involved in the flow of the glacier (Fig. 5).

## *GLACIER MOVEMENT*

I make no apology for dealing with the subject of glacier movement at some length, since it has excited more controversy in glacier study than any other subject. Although there is a voluminous literature on the question of the precise mechanism involved in the movement of glaciers, the two main schools of thought may be exemplified by the publications of von Engeln and Chamberlin. Von Engeln voiced the feelings of those who believed that the glacier flowed by plastic, viscous yield, the crystals growing and shifting in relationship to each other through the medium of brine which he and others maintain surrounds them. Chamberlin, on the other hand, supported the sliding of the whole body of ice over the rock beneath, accompanied by inter-

mittent slip along thrust planes, accompanied by solid shearing of aggregates of granules and lastly solid flow by ideomolecular exchange between ice crystals.

*Plumb line and pin experiments in the* névé *region.*—We entered upon this field with minds entirely open. Our first attempts at solving the problem were to find out by empirical means what was the nature of the differential motion of the glacier. To this end we made experiments in one of the pits. These consisted of embedding steel markers in a vertical section in the firn and watching, by means of plumb lines, the relative day-to-day movement of the various markers. These gave us such baffling results, some points moving forward and some seeming to move backward, that it became necessary to use a line of pins stuck in the firn at about 1 centimetre intervals along the plumb line over a length of 2·2 metres. Four days later we found the same irregular state of affairs, but in a form now more easily understandable. Some of the pins had moved forward relatively to their neighbours, and others had naturally moved relatively back (Publ. No. 1, 348).

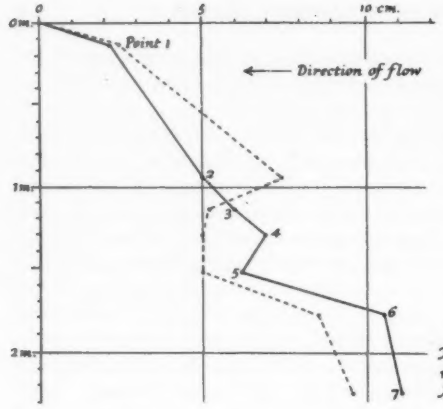
The immediate question presented itself: Was this relative movement confined to crystals or aggregates of crystals or did it take place in layers? To settle this point we stuck in further lines of pins, parallel to the first and quite close to them, at places where the most violent movement had taken place. The results indicated that no forward movement in any one line was echoed by a forward movement in any neighbouring line, and the motion is therefore confined to individual crystals or groups of crystals.

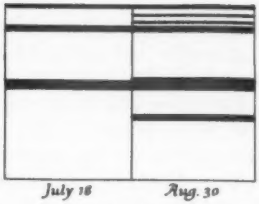
To make this point further evident we made a lattice of pins which some days later assumed the appearance shown in Fig. 6. It will be observed that in certain of the lines the movements have been slightly echoed in neighbouring lines and then fade away, giving the impression that movement is at this point taking place in clusters of crystals, not by individual crystals, but certainly not in layers of any appreciable area.

*Crystallographic confirmation.*—Let us look at these results in the light of our crystallographic investigations. It is believed that when snow falls to earth its crystals lie orientated in every direction, without rule or order. So far as we could confirm this view we did, although to go any great distance in this direction raises great technical difficulties. As soon as we went down the glacier a little way and dug into it, the crystals of firn were found to have acquired a definite orientation, perpendicular to the glacier surface.

It was soon realized that this effect was not a local one and that everywhere at about this depth the crystals possessed the same orientation. Eventually it was found that the cause of this effect is similar to that giving rise to growth orientation in pond ice or cast metals, the crystals simply growing with their main axes parallel to the direction of the temperature gradient, which is in this case perpendicular to the glacier surface.

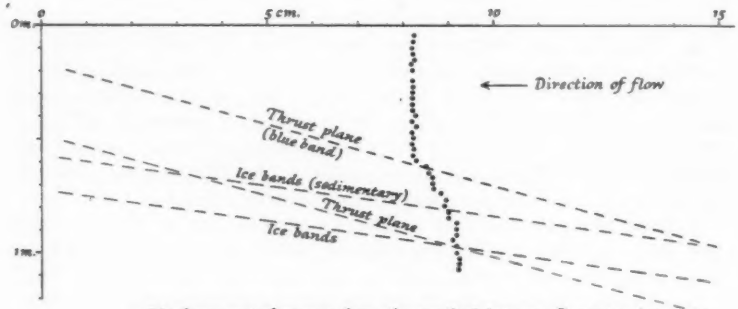
In order to obtain samples of the firn at greater depths and at different positions in the glacier, crevasses were entered by means of a rope ladder and specimens were hacked out of the walls. In taking these samples great care was taken to ensure that they were not weathered, that is to say, they represented the firn in the interior of the glacier. They were marked to indicate the



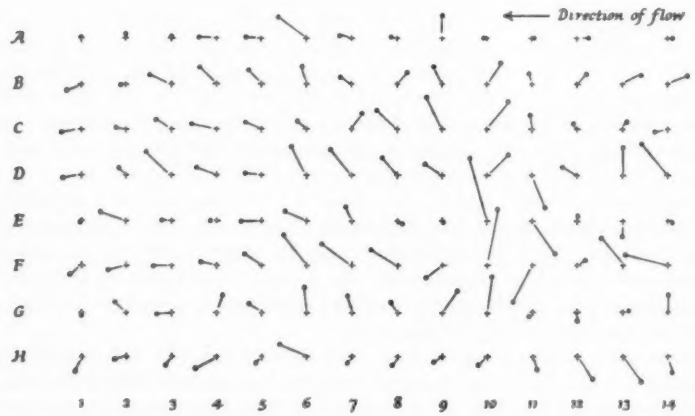




*Ice bands in downstream wall of Auxiliary Pit No. 1*

*Movement of two sets of seven points with respect to two plumb lines Auxiliary Pit No. 2*




*Displacement of screws from the vertical between Aug. 17 and 31 Grotto in snout of Eigergletscher*




*Lattice of pins set 1 cm. apart Aug. 8: movement by Aug. 23 shown by ✓*

*Fig. 6*

direction of glacier flow and the position of the plane parallel to the surface of the glacier. The possibility of any recrystallization taking place before the specimens were examined in the cold laboratory was completely avoided by transporting them in thermos flasks containing a few lumps of solid carbon dioxide (Dricold). The technique of section cutting and determination of the crystal axes has been described more fully elsewhere (Publ. No. 1, 339).

At 14 metres a certain amount of scattering from the vertical is noticeable; at 23 metres the aspect has changed entirely. Only a few clusters of crystals have retained their orientation near the vertical line, while the others are scattered over almost all possible angles. At greater depths below the surface, implying longer subjection to the influences of flow, we invariably found the orientation gradually reverting to haphazard arrangement.

We then studied the ice-bands which grow so frequently among the loose-grained *névés*: bands of dense, practically air-free ice crystals. Here the orientation was invariably such that the crystals had their main axes perpendicular to the surface of the ice band. This never varied, however far the ice had flowed. In such a band at 23 metres depth the crystals are regularly orientated, but of quite haphazard orientation in the neighbouring *névé*. This transition from order to disorder in the firn, coupled with the preservation of order in the ice band, suggests that in the firn, where the crystals are in relatively loose contact, single crystals or clusters of single crystals can move independently and alter their relative positions, while their close packing in the ice bands prevents any movement, and thus preserves their original orientation.

*Experiments in the glacier tongue.*—All the above, of course, takes place in the *névé* area, and we naturally wanted to know what happened in the glacier tongue. As there was a convenient grotto dug in the tongue of the Eigergletscher at an altitude of about 2300 metres, it was possible to make the experiment in a vertical face in the moving part of a glacier tongue. It was found that a line of screws had to be used instead of a line of pins, since the latter were squeezed out overnight by the pressure in the ice. Even with screws it was necessary for them to be screwed up every few days for the same reason. After some days we observed movement of our screw lines, but quite different from that of our pin lines. There appeared to be no relative movement of the screws, but the whole of an upper layer appeared to have slipped downstream over a lower one (see Fig. 6).

The two series of such experiments in firn were carried out quite independently, the pin experiments by myself and my assistants, and the crystallographic by Dr. Perutz, and it is striking that they have supported each other so well. Both series show that in those areas of the *névé* investigated the crystals or crystal clusters are the units of movement.

In ice, on the other hand, where it would be reasonable to suppose that the crystals are closely packed together and cannot move independently, the screw experiments supported this supposition, for in the case of the screws the movement we found was by layers of ice with no change in the position of individual crystals.

Our crystallographic examination of the ice in the glacier tongues showed us that, quite contrary to the opinion of practically every glaciologist heretofore, with perhaps the exception of von Drygalski, the ice crystals are orientated or have a tendency towards orientation.

Now Bader and Haefeli [1] have recently shown in the laboratory that when ice is subjected to stress the crystals, previously arranged haphazard, arrange themselves into a regular order; thus what we found has useful confirmation. Better known perhaps is the analogy of crystal orientation following the deformation of metals by cold working.

This tendency towards orientation of the crystals in the ice of the tongue of the glacier is quite definite evidence that a gradual process of plastic deformation must continually be going on under the influence of internal stresses. Since the ice crystals are not able to slide over one another as they can in the firn, the individual crystals deform plastically, presumably in the same manner as in metals, where parts of the crystal undergo motion relative to each other over well-defined slip-planes. This mechanism of glacier flow is quite distinct from that in the firn, where the units of motion are crystals or crystal aggregates, and distinct also from the large-scale shearing of masses of ice which was also observed in the glacier tongue.

To sum up, it will be seen that in the *névé* area we have, as the principal mode of flow, movement by units of crystals or clusters of crystals, and in the ice region we have flow both by slip of layers upon one another (laminar motion) and by plastic deformation of the individual crystals, accompanied by crystal growth. It thus appears that the two opponent theories of the mechanism of glacier motion will require considerable alteration, and that neither of them can claim to hold the field against the other, since this research has, I hope, been successful in demonstrating that both mechanisms exist.

*The influence of plastic deformation on grain growth.*—In the case of metals the heating or annealing of a cold-worked specimen is accompanied by an increase in the grain size, due to certain crystals growing at the expense of others. During the flow of the glacier the conditions are analogous to those of a metal being deformed above its annealing temperature, and an appreciable grain growth might be anticipated. This was, in fact, the case, for as Plate 26 shows the grain size in the ice from a serac in the glacier was appreciably greater than that of the ice in the *névé* region. In order to understand how this grain growth can come about, it is worth quoting the simple picture proposed by Perutz. "It would appear," he states, "that crystals whose orientation allows them to yield to shearing forces by glide along the basal plane are subjected to a relatively smaller pressure than crystals in a different position which cannot yield. The former would therefore possess smaller free energy than the latter, and would have a tendency to grow at the latter's expense, by transfer of molecules across the crystal boundaries. The growth of the crystal in the ice region is thus due to differences in the energy content of neighbouring crystals."

Thus it will be seen that our observations in regard to glacier flow have led us to understand the general tendency in the glacier for the grain to increase

[1] Bader and Haefeli, Beitr. Geol. Schweiz., Geotech. Ser., Hydrol., Pt. 3, Bern, 1939.

in size. In the early stages some melting and refreezing of melt-water causes a certain increase in the grain size, and the density of the firn mass is concurrently increased by this and by settling. The crystals are however free to move relative to one another, and that is why nowhere do we find grains of great size. Moreover in all newly formed ice which we examined the crystals were still comparatively small. It is only after the ice has existed for some time and has been subjected to the stresses incident to the glacier flowing down its bed that they grow by what we may term selective orientation of those most favourably placed, at the expense of those less favourably placed, in the manner I have described above.

My personal view is that this does not fully explain the very large crystals found in dead ice or in the snouts of glaciers. My belief is that an added stimulus is given by alternate melting and refreezing, accompanied, no doubt, by variations in the vapour pressure of crystals of different sizes by which the larger crystals absorb the smaller. The mechanism is simple: freezing melt-water must attach itself to an existing crystal and go to add to the structure of that crystal; therefore if during a day's thaw any crystal goes over entirely into melt-water it will attach itself on refreezing at night to another crystal and go to increase its size, the original crystal disappearing. I am proposing to make the growth of the crystal grains in glacier tongues the subject of my next research.

## *THE INTERNAL STRUCTURE OF AN ALPINE GLACIER*

During the course of our many wanderings over the Aletsch Glacier we made careful surveys of the nature of the firn and ice vertically downwards, as shown by crevasses into which we descended, and in the shaft which I have already described. From measurements made in crevasses at different depths, from close to the firn line nearly to the glacier source, we obtained the following results. In the lowest crevasse, 100 metres above the firn line, ice was found at 11 metres; at 3200 metres, just below 16 metres; at 3330 metres, at 20 metres; and at 3450 metres no ice was visible at all. From this and other data we were able to construct a longitudinal section through the glacier which is shown in Fig. 7. I cannot go into the evidence from which I have drawn the glacier bed. It is based on deductions too long to enter into here, but it cannot be very badly amiss.

At the firn line there is of course no firn at all, but as the *névé* area is ascended the firn becomes an ever-increasing wedge. When however we reach an altitude of 3450 metres no ice is to be found, even at a depth of 30 metres, and we have to ask ourselves whether there is really any ice at this altitude at all or whether the firn extends to the bottom of the glacier.

We have seen that below 15 metres the temperature of the glacier never falls below 0° C. Now the annual excess of accumulation over ablation at the Jungfraujoch is about 3–5 metres or more. Since the temperature below 15 metres is never below melting-point, water cannot be frozen into ice beyond that depth, and this would leave only four or five seasons before it became covered with sufficient snow to remove it from further freezing influences and thus prevent it from turning into ice at all.

Of course below this depth the pressure of the firn may become so great

that ice is formed by pressure alone. We made certain rough measurements in this direction which showed that grains of firn tended to flow together in proportion to the pressure, temperature, and time, and it may therefore well be that near the glacier bed a tongue of ice protrudes. Colour is lent to this view by the distinct asymptotic nature of the curves which show specific gravity against depth. This can be seen in our own results found in the shaft (Publ. No. 2, 640), and in those of Sorge in the Ice Cap.

*Glacier bands.*—There has been almost as much controversy on the nature of glacier bands as there has been on the nature of glacier flow. We spent a good deal of time watching and measuring from day to day bands in course of formation in the *névé* area, and we have been able to distinguish two quite separate types.

The first are the so-called annual bands which appear brownish in a section

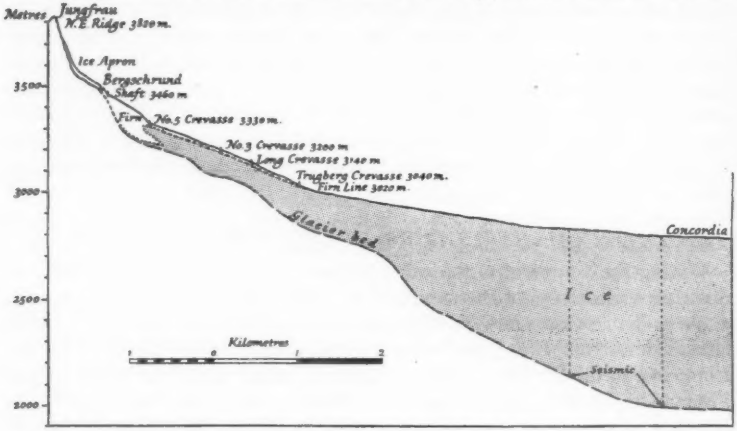



*Fig. 7. Upper Aletsch Glacier, hypothetical section*

of the firn and are due to deposition of dust and detritus during the summer months when snow falls are slight and rocks are exposed. They are well seen in Plate 29.

The second type is due to the retentive capacity of snow. In Publ. No. 2, 638, we have been able to show that water tends to collect in the denser layers of snow. The alternation from dense to less dense layers is most striking. When one of these thicker laminae becomes buried below the surface and receives melt-water from above, this water collects therein and in the next frost freezes to form an ice band. The mechanism of this process was originally suggested by Wright and Priestley, and later by Paulcke. More water may collect in what was the surface crust, now buried a few inches below the surface. Plate 30 shows a band of this type in a crevasse wall.

Unless an ice band is fairly rigid, that is to say fairly thick and dense, the movement of the individual firn grains, which I have described above, distributes it, and this accounts for the curious effect, originally noted by Whymper and often seen by ourselves, that the deeper you penetrate into the

*27. Melt-water runnels on surface of firn*

*28. Meteorological station and shaft, Mönchfirn: Note*

*29. Four annual bands in Crevasse H: Note*

*30. Ice band 70 cm. thick, and surface crusts*

*névé* area the comparatively fewer are the numbers of ice bands, and that only the bigger ones persist. Ice bands have a hitherto unsuspected effect on the flow of melt-water in glaciers. As they impede the downward flow of water they impart to it a considerable horizontal component.

In the glacier tongue we found three types of bands, the survivors of the sedimentary bands of the *névé*, the traces of filled-up cracks and crevasses, and finally those which develop in the tongue itself by shear in thrust planes.

*Notes on certain plates in amplification of title*

No. 1 looks north towards the Mönch. In the foreground there is the Sphinx rock with the new observatory on the summit, and the research institute and hotel at a lower level. The Jungfraujoch is the saddle below the Mönch and to the left of the Sphinx. In the left distance the Eiger can just be seen. On the right of the photograph there is the Mönchfirn, and in the foreground the Jungfraufirn. The cross marks the position of the cold laboratory.

No. 2 is a view of the ice apron on the north wall of the Sphinx. Patches of ice formed from frozen melt-water appear grey against the whiter snow. The building on the summit of the Sphinx is the new observatory. In the left distance part of the Trugberg can just be seen.

No. 10. The ice-drill on the right was most successful.

No. 12. The smaller spoon, $15 \times 1\frac{1}{2}$ inches, was principally used.

No. 13 shows specific gravity shells. The shell on the left was used in firn, and has a saw edge, two plates, and a hole for a tommy bar. The shell on the right was used in snow and has a longitudinal slot at the top, and single plate, and cutting edge below.

No. 14. The coring head on the left acted best.

No. 28. In the foreground the meteorological instruments are in a line leading from the shaft. The Gletscherhorn is in the left distance, the Rottalhorn in the right centre, and the base of the Jungfrau pyramid on the extreme right.

No. 29 is taken in crevasse H. Four broad annual bands are shown; two of these are above the hammer which the man is holding, and two are below, the position of the lowest band is indicated by a pointer. To the right of the figure there are mushroom-topped ice bands.

## DISCUSSION

Before the paper the Secretary said: Mr. Wordie, who will be taking the chair at our meeting this afternoon, has been detained at an important official conference. He has asked me to introduce to you Mr. Gerald Seligman, whom most of you know very well, and who is Chairman of the British Group of the International Commission of Glaciers and Snow. He had the excellent idea to organize an important research upon the Jungfraujoch which was carried out in 1937–38. One of the reasons for choosing the Jungfraujoch was that it was comparatively accessible and moreover it was possible for a party to live there, at a great height, with the glacier within easy reach, in all the comfort of civilization, including a laboratory excavated in the ice which maintained itself at a temperature several degrees below zero Centigrade.

Mr. Seligman had with him a strong team of specialists in the various departments of the work. He will now give a general account of their research and will be followed by Dr. Hughes of Gonville and Caius College, Cambridge, and by Dr. Max Perutz.

*Mr. Gerald Seligman then read the first part of the paper printed above, and was followed by Dr. T. P. Hughes and Dr. Max Perutz, who spoke on those parts of the work in which they were more immediately concerned.*

The SECRETARY: Apparently Mr. Wordie is still detained and unable to get here to take his place, as he had intended, as Chairman of this meeting. We have much to thank Mr. Seligman and his team of scientists for. There should be some members of the audience who desire to ask questions in the relatively limited time remaining. Are there other members of the British Group of the Commission of Glaciers and Snow who would like to speak?

Dr. RICHARD SELIGMAN: When Dr. Perutz was discussing the plastic flow of the snout of the glacier he spoke of the crystals growing at the expense of others, partly I gather owing to the melting of the smaller crystals and re-crystallization of the larger ones later. Is it not a fact that in the snout of the glacier there is a deformation of the crystals generally and then, owing to temperature changes, re-crystallization at the expense of the crystal breccia—I think that was the word he used—the small crystals being broken up on the margins of the large ones. It is not necessary to assume actual melting but merely changes of temperature following the movement of one crystal with respect to another. That, if I am not mistaken, would be the true analogy. I recall that this point was on one occasion discussed at considerable length on the top of the Jungfraujoch.

Dr. PERUTZ: I do not say that actual melting ever takes place, but that what happens is transfer of water molecules from one crystal to another. One crystal becomes strained very much. The crystal hardens, and there is a limit to the strain to which it can be subjected. When that limit is reached it is probable that another crystal near by would be in a more favourable position to be deformed, and that crystal would grow at the expense of the other. Is that acceptable?

Dr. RICHARD SELIGMAN: Yes, I think so.

Dr. SPENCER: If the crystals vie with one another, what is the size of the biggest crystal in any part of the ice?

Mr. G. SELIGMAN: Dr. Perutz said that some were as large as melons. I have never seen any so large, but I have seen them as large as one's forearm. If you search for them, you will probably find large crystals in special places, such as little recesses where the glacier stops flowing. These have grown from the smaller crystals, originally single snowflakes.

Mr. HINKS: I was not clear how Dr. Perutz distinguished the two kinds of bands, those connected with laminar motion and those of sedimentary origin.

Dr. PERUTZ: There is one set which apparently is of sedimentary origin: in this set the blue bands are all parallel with each other. There are certain other blue bands which do cross over. Sedimentary blue bands never cross: they must all be parallel to the original surface. I think it is safe to assume that the first set are sedimentary and the second are tectonic.

Dr. S. E. HOLLINGWORTH: Is there any possibility that a regular series of dirt bands, such as those found in the Greenland glaciers, can be formed by laminar flow?

Dr. PERUTZ: It is possible of course, but we have no observation of any one particular structure whereby we have proved that the dirt bands in the glacier can be formed by laminar motion. We however saw something we suspected to be of that particular nature. There can be melts inside the glacier, and if there is a thrust band the debris from the surface may be carried up.

Mr. GERALD SELIGMAN: In many of the Arctic glaciers we know that has happened. I have in mind Wegener's deposition. We actually saw that happen.

Mr. BONACINA: When I received notice of Mr. Seligman's paper I was puzzled by the word "temperate." I would ask Mr. Seligman what emphasis he would place on that and whether it would not be wiser to call it an "Alpine glacier." I cannot help feeling that the hidden structure which Mr. Seligman has revealed may be quite closely related to climatic conditions, and I am wondering what he might have found in the Pyrenees where some of the *névé* fields are much smaller and summer melting much greater; or what kind of result he would get in Southern Chile where precipitation is enormous. As for problems in viscous flow, I wonder whether the structure of a glacier has been compared with that of a solidified lava stream. I believe some lava streams also show laminated bands. It seems that if the two phenomena were studied together they might throw light on one another.

Mr. GERALD SELIGMAN: I think there is a good deal in what Mr. Bonacina says. I personally have no data and really no idea what one would find in one of the Chilean, or even in one of the Himalayan glaciers. Perhaps we used the word "temperate" rather loosely. As to the analogy between a lava stream and a glacier stream I am not sure how far that would be helpful. In a glacial stream there is the opposite: a melting effect as the glacier proceeds downwards. I do not know whether Dr. Perutz has any views on the point.

Dr. PERUTZ: I think experiments have been made on pitch, and its behaviour, taken as a whole, was much the same as that of the glacier, but I do not think it showed any lamination bands.

Miss D. R. CROWFOOT: Is the formation of the blue band in the glacier similar to the formation of the ice band in the firn?

Dr. PERUTZ: Blue bands in the ice are mostly remnants of the ice band in the firn. There could not be deformation in the ice bands because their formation is of necessity permeable to melt-water, which ice is not.

The Chairman invited Mr. Seligman to make a concluding statement.

Mr. GERALD SELIGMAN: We have reached what are to us very definite results. We were in the course of working them out and bringing them into proper and logical sequence when war broke out and prevented us doing anything very elaborate. It has been a little difficult to sum up all our results. From that point of view it may be thought that the results as we present them are not in correct sequence and not fully elaborated. That, I am afraid, is only an accident of the times in which we live. Only time will remedy that, but I think in general we have been able to give a scientific basis to a good deal that was previously supposition. It seems to me that the failing of glaciological research is that there has been a great deal too much of "it depends on." We can claim that our work was based on scientific facts and deductions made from actual observation and not supposition. Beyond that we cannot go at the present stage. We are awaiting, as so many others are, an opportunity to get on with our more legitimate work.

The SECRETARY: The time has come when we must bring this discussion to an end. I regret very much that Mr. Wordie has not been able to get here to say how greatly the Society is indebted to Mr. Seligman and his team for a paper which covers more ground of interest than I can remember for a long time. It will be a serious responsibility cast upon the Editor of the *Journal* to do justice to the paper without filling several journals with it, because however valuable and interesting the paper it could not be published in full. Mr. Seligman, the principal author, is far away from London, but Dr. Hughes has already kindly assisted me and I am sure will continue to do so, so that we can eventually in the publication of the paper do justice to the remarkable performance of this team, working, as we were assured by Dr. Perutz, in all the comforts of civilization.

# REVISION OF THE R.G.S. II SYSTEM

The R.G.S. II Table of Spelling and Pronunciation, last issued as a leaflet by the P.C.G.N. in 1932 and reprinted in simplified form on pp. 215–7 of 'Hints to Travellers,' 11th Edition, 1938, is affected by several decisions of the P.C.G.N. already announced (*Geogr. J.* 91 (1938) 158–9, *G.J.* 92 (1938) 446–8), and by the new rules for the transliteration of modern Greek now in official use (*G.J.* 97 (1941) 156–7). As modern Greek is written more strictly in accordance with the R.G.S. II System by the new rules than by the old, their provisional status does not affect the System. It is appropriate therefore to bring the R.G.S. II Table of Spelling and Pronunciation into the corrected form given below. More general questions involved in British practice in the writing of geographical names, now being examined, will be the subject of a further statement.

## Table of Spelling and Pronunciation R.G.S. II.

| | | |
|---|---|---|
| **a** | The long and short Italian vowels, as in *lāvă* | Somāli, Răvennă.[1] |
| **ä** | Between *a* in *fat* and *e* in *eh?*; chiefly in Teutonic and Finno-Ugrian languages .. | Mähring, Pärnu. |
| **ai** | The two Italian vowels, frequently diphthongal almost as in *aisle*; but pr. *ei and ĕ* in Greek names .. .. .. .. | Wadai; Shanghai. |
| **au** | The two Italian vowels, frequently diphthongal almost as *ou* in *out* .. .. | Sakau; Bauchi. |
| **aw** | When followed by a consonant, or when terminal, as in *awl, law* .. .. .. | Dawna, Saginaw. |
| **b** | As in English. | |
| **c** | Not to be used, but always replaced by *k* or *s*; except in the compound *ch*, and in many conventionally-spelt words, as .. .. | Kabul, Serang. Calcutta, Celébes. |
| **ch** | As in *church*; never *tch* or *tsch* for this sound | Chad, Kerch. |
| **d**[2] | As in English. | |
| **dh** | Soft *th* as in *they*; a slight *d* sound sometimes preceding it in Semitic languages .. .. | Hadhramaut, Riyadh. |
| **e** | Long as in *eh?*; short as in *bet*. (For the *e* sound in the French *je*, see note at end on the "neutral vowel") .. .. .. | Gĕlo; Maĕfking.[1] |
| **(ee)** | Used for *i* (*q.v.*) only in a few conventional names .. .. .. .. .. | Darjeeling, Keelung. |
| **ei** | The two Italian vowels, frequently diphthongal as in *rein*; but pr. *i* in Greek names | Beirut, Raheita. |
| **(eu)** | Not used as a single sound. | |
| **f** | As in English; *ph* must not be used for this sound .. .. .. .. .. | Mustafa, Maidan-i-Naftun |

[1] The long and short symbols given here are merely for explanation, not for use.
[2] See note at end on *Liquid sounds*.

| | | |
|---|---|---|
| **g** | Hard, as in *get, gift*; never as in *gem, gin* .. | Gedáref, Gilgit. |
| **gh** | Soft guttural, the Arabic *ghain* (غ) .. .. | Ghadames, Baghdad. |
| **h** | Used only when sounded; or in the compounds *ch, dh, gh, kh, sh, th, zh* .. .. | Ahmadabad, 'Abdullah. |
| **i** | Long as in *marine*; short as in *piano* .. .. | Fījī; Kibonde.[1] |
| **j** | As in English; except in transcription of Chinese, where it equals *zh* or the French *j* | Juba, Ujiji (Eng. *j*); but Jaoping (Fr. *j*). |
| **k** | As in English: hard *c* should never be used (except in conventionally-spelt words)—thus, not Corea, Cabul, but .. .. | Korea, Kabul. |
| **kh** | Hard aspirated guttural, as in the Scottish *loch* (not as in *lock*) .. .. .. .. | Khan, Sebkha. |
| **l**[2] **m n**[3] | As in English. | |
| **ng** | Has three separate sounds, as in *vanguard, finger*, and *singer*. If necessary to distinguish, a hyphen may be placed, as in *van-guard, sing-er* .. .. .. .. | In-gall; Bongo; Ng-ami, Tong-a. |
| **ngg** | May be used for the sound of *ng* as in *finger* .. | Trengganu, Yanggang-a. |
| **o** | Long as in *both*[3]; short as in *rotund* .. .. | Kigōma; Hŏnolulu.[1] |
| **ō** | As in German; equals the French *eu* in *peu*; or nearly the English sound in *fur* .. .. | Barkŏl. |
| **(oo)** | Used for *u* (*q.v.*) only in a few conventional names, chiefly Indian and Chinese .. | Poona, Foochow. |
| **oi** | The two Italian vowels, frequently diphthongal as in *oil*; but pr. like *i* in *fit* in Greek names .. .. .. .. | Hanoi. |
| **öi** | The diphthong as in French *œil* and Norwegian *hōi* .. .. .. .. .. | Hōiland. |
| **ou** | Dissyllabic, and not as French or English *ou* except in Greek names, where it has the French value .. .. .. .. | Zlatoust, Yaroua. |
| **ow** | Used as a diphthongal combination of *o* and *w* *only* in the romanization of Chinese. | Hankow. |
| **p** | As in English. | |
| **ph** | As in *loophole*; not to be used for the *f*-sound except conventionally .. .. .. | Chemulp-ho; Haiphong. |
| **q** | Represents *only* the Arabic *qaf* (ق) and the Hebrew *qof* (ק): *i.e.* a guttural *k* (as a rule) | Qena, Qiryath. |
| **qu** | Should never be employed to represent the sound of *kw*: thus, not Namaqua, Quorra, but .. .. .. .. .. .. | Namakwa, Kworra. |

[1] The long and short symbols given here are merely for explanation, not for use.

[2] See note at end on *Liquid sounds*.

[3] The true Italian *ō* is broader than this: almost as in *broth* (=R.G.S. II *aw*). The letter *o* is conventionally used for this sound in certain names in Nigeria, Tonga, etc.: *e.g.* Oyo, Fofoa.

| | | |
|---|---|---|
| **r** | As in English; should be distinctly pronounced. | |
| **s**[1] | As English ss in *boss*, not as in *these* or *pleasure* .. .. .. .. .. | Burgos, Masikesi. |
| **sch** | As in *discharge* .. .. .. .. | Peschanka. |
| **sh**<br>**t'** | As in English. | |
| **th** | Hard *th* as in *thick*, not as in *this* (except conventionally in Fijian) .. .. .. | 'Athlith, Thingvellir. |
| **u** | Long as in *rude*, or as *oo* in *boot*; short as in *pull* .. .. .. .. .. .. | Zūlū; Rŭanda.[2] |
| **ü** | As in German; equals the French *u*, as in *tu* | Üsküdar. |
| **v**<br>**w**<br>**x** | As in English. | |
| **y** | Always a consonant, as in *yard*; it should not be used as a terminal vowel, *e* or *i* being substituted; *e.g.* not Kwaly or Wady, but | Kikuyu, Maya.<br>Kwale, Wadi. |
| **z** | As in *gaze*, not as in *azure*. | |
| **zh** | As the *s* in *treasure*, the *z* in *azure*, or the French *j* in *je*; but for the sound in Chinese use *j* (*vide* note above under *j*) .. .. | Zhob. |

NOTES

| | |
|---|---|
| The doubling of a vowel or a consonant is only necessary when there is a distinct repetition of the single sound, and should otherwise be avoided .. .. .. .. .. | Nuusafee, Moorea, Jidda, Muhammad. |
| Accents should not generally be employed; but in order to indicate or emphasize the stress, an acute accent may be used .. | Saráwak, Qántara, Tong-atábu, Paraná. |
| A long or short mark over a vowel (*e.g.* ā, ŏ) should only be used (and that sparingly) when without it there would be danger of mispronunciation .. .. .. .. | Kūt, Kyōto, Abŏso. |
| Hyphens will not be used except to indicate pronunciation or with the particle *-i-* (in Persian, Fijian, etc.) .. .. .. | Ta-if; Pusht-i-Kuh, Nuku-i-Ra. |

**Inverted comma and apostrophe.**—The inverted comma ' is employed only to represent the Arabic *'ain*, ع, the Maltese *għain*, *għ*, and the Hebrew *'ayin*, ע. The apostrophe ' in foreign words indicates a liquid sound (see below).

**Liquid sounds.**—The occasional "liquid" or "palatalized" sound of *d*, *l*, *n*, *s*, *t*, etc. (as in *d'you*, *lure*, *new*, *pursue*, *tune*, etc.) is as a rule sufficiently represented by a following *y*; where however owing to a following consonant,

[1] See note at end on *Liquid sounds*.

[2] The long and short symbols given here are merely for explanation, not for use.

or to the palatalized letter coming at the end of a word, the *y* is inapplicable, the liquid sound will be represented by an apostrophe, thus: *d'*, *l'*, *n'*, *s'*, *t'*, etc.

**The "neutral vowel."**—The "indeterminate" or "neutral" vowel sound (*er*), *i.e.* the sound of *a* in *marine*, *e* in *often*, *i* in *stir*, *io* in *nation*, *o* in *connect*, *ou* in *curious*, *u* in *difficult*, etc., *e* in French *je*, or the often unwritten vowel (ˊ *fat-ha*) in Arabic, etc., is represented as a rule by *a*: as in Basra, Hawiya; but sometimes by *e*, when the sound approximates more to *e* than to *a*: as Meshed, El Gezira.

(In any guide to pronunciation issued by the Permanent Committee on Geographical Names, the "neutral vowel" is represented generally by the italic *e*: occasionally also by italic *a* or *u*.)

This sound must not be confused with *e-mute*, where the *e* is not sounded at all: as in Abbeville.

**Nasal vowels.**—In illustrating the pronunciation of French, Portuguese, Polish, etc., nasal vowels, the nasalization will be represented by italic *n*: as Częstochowa, pr. Chănstokhóva.

M. AUROUSSEAU,
Secretary, P.C.G.N.

Royal Geographical Society, Kensington Gore, S.W.7.
May, 1941.

# THE NATURAL RESOURCES OF TRANSJORDAN

REPORT ON THE WATER RESOURCES OF TRANSJORDAN AND their development. By M. G. Ionides. Incorporating a report on GEOLOGY, SOILS, MINERALS, AND HYDRO-GEOLOGICAL correlations. By G. S. Blake. *London: Crown Agents*, 1940. 13×8 *inches;* xxiv+372 *pages; illustrations, folding-maps, and diagrams.* 30*s*

THIS comprehensive well-printed publication of the Transjordan Government is appropriately described by its title. Liberally illustrated with photographs, maps, and diagrams, some 264 pages of text are devoted to describing the hydrography of the country in all its varied aspects; but a further 104 pages are taken up with appendices, tables, figures, and plates, which reach a total of 238.

Evidently no pains have been spared to reach a reasoned conclusion regarding the practicability of improving agricultural practice in a country which has always suffered from an insufficiency of rainfall. The pacification of a virile but turbulent and restless population largely depends upon an improvement in the standard of living, and this, in its turn, necessitates land settlement and the growth of crops to support larger numbers with more and varied food.

Transjordan is described as a country with an area of 90,000 km.$^2$ and a population of about 325,000, or 3·6 per km.$^2$, but no less than 95 per cent. of the land is regarded as unsuitable for growing crops; therefore pastoral and nomadic habits are enforced on the occupants. Rainfall is low and capricious in distribution, aggregate precipitation, and incidence, and there are few perennial streams available for irrigation even if suitably located land existed. The Rift Valley carries away almost the whole drainage of the country and the wadis, which are deeply eroded in its sides, pierce water-bearing horizons and drain high-level ground-water supplies which would otherwise be preserved for use on the uplands. Emphasis is placed on the varied character of the climate in this small country, owing to extremes of altitude between the Dead Sea, 1200 feet below and the plateau about 2000 feet above sea-level; and also on the changes wrought by distance from the Mediterranean as well as the position of the Judean Hills, which trap the moisture-laden winds before they reach the Jordan valley. Apart from other considerations rainfall, as would be expected, is shown to bear a close relationship to topography, being heaviest on the highest ground and lowest in the depressions. Rainfall shades away eastwards and southwards to an insignificant amount with a gradual change to desert conditions.

From correlated measurements it has been ascertained that only about one-tenth of the country, or say 9061 km.$^2$, receives a rainfall in excess of 200 mm. a year, an amount that is regarded as the minimum required for dry farming; but owing to rugged topography and other causes the cultivable area is estimated at only 4490 km.$^2$, of which 260 km.$^2$ are irrigated. The belt of cultivable territory, where the average annual rainfall is 360 mm., runs parallel with and not far to the east of the Jordan and Dead Sea, but is mainly centred at the north end. The average rainfall on about double the cultivable acreage in Palestine is stated to be 520 mm.

The calculated area of the Dead Sea drainage system is 40,650 km.$^2$ of which 16,730 km.$^2$ drains into the Jordan above the Allenby Bridge on the Jerusalem–Amman Road, and of this 21,910 km.$^2$ are in Transjordan. The annual Transjordan run-off is given as an average of 581 million cubic metres, of which about half is derived from perennial springs, but much of this water flows in steep valleys between sharp ridges with no terraces or flats suitable for cultivation.

The river Yarmuk with its catchment of 7250 km.², and an average annual discharge of 480,000,000 m³, is the only important source of water that could be put to useful purpose for irrigation, and it is considered that a high-level canal could be arranged to irrigate about 40 km.² of land in the Jordan valley. This river is fed by large springs issuing from the base of basaltic lavas in Syria. Unfortunately the Yarmuk has become an integral part of the works designed to ensure a more equable supply of water for the Palestine hydro-electric station at the southern end of lake Tiberias. Before the construction of the dam the flow of the Jordan at the outlet of lake Tiberias varied from about 60 m.³/sec. in March to as low as 2–5m.³/sec., or even nil in September–October. Now the situation is reversed, as the Yarmuk water is used for power in the flood season and that of Tiberias conserved until it is needed in July, August, and September to supplement the falling flow of the Yarmuk. The ratio of run-off to rainfall on the Yarmuk catchment is given as 18·2 per cent.—a remarkably high figure.

In the Jordan valley some 20 km.² of land now overgrown with reeds or forests is suitable for cultivation if cleared, but that nearest the river is liable to flooding. On much of the valley the lift is too great for economic irrigation by pumping. Four pumping units are in operation for irrigating 1080 acres, but owing to the deep channel in which the Jordan flows, a lift of from 50 to 100 m. is generally needed to put water on the lowest terrace.

Some 50,000 acres of land, mostly in the Ghor, are irrigated by twelve spring-fed streams aggregating 157,000,000 m.³ a year that flow in wadis reaching the valley. The locations of seventy-nine discharges are shown in Fig. 5. Only a few springs issue from fissures: most occur as seepage belts where the water-bearing stratum has been exposed by erosion. Of the twelve flowing streams the chief is Wadi Zerqua with a dry season discharge of 1 m.³/sec. The next largest is Wadi Hisa with ¾ m.³/sec. dry season flow.

Careful run-off measurements were made on an 82 km.² catchment at Amman, but a storm of unusual severity probably rendered the results misleading. The run-off was 12·6 per cent. of the rainfall, and the silt volume carried in suspension was equal to a removal of 0·11 mm. In some years there may be no run-off from catchments where rainfall is in light showers.

A fair number of boreholes have been sunk in the country to explore for ground water, and the sections with details are given in the Appendix, but in nearly all cases the static level was either too low for economic irrigation or the rate of infiltration too slow to give useful quantities. The logs of forty wells are given, of which twenty-two are pictorially represented on folded sheets. Unfortunately the lithological conditions in the Jordan valley do not favour well-sinking, for on the alluvial fans and sloping sides of the Rift valley, where the detrital sediments are coarse and highly permeable, the water table is too deep; and further removed from the Scarp these free-yielding gravels and sands feather out into fine-grained deposits that will not yield freely, and in addition the water usually contains salts injurious to plant life. For domestic uses boreholes and shafts have given general satisfaction, for except in the Ghor all waters of the country are sweet and potable except the hot mineral springs. It is pleasing to find that the construction of *kharezes* (infiltration galleries along watercourses) is discouraged by the author. This was a very common ancient practice in the Middle East, but is open to the serious objection that water is drawn off catchments when least wanted in the rains, leaving less for the dry season when most is wanted by agriculturalists. Naturally the value of water to an agricultural community depends upon many circumstances, such as soil fertility or its suitability for selected crops and rotations, climatic conditions, proximity to markets, etc.; but as the present average farm holding is only

21 acres compared with 35 acres in Palestine, it is clear that the cultivators could not afford to use water that was costly to purchase or expensive to raise. The author considers the economic range of water costs to lie between extremes of 3 mils and 1/10th mil per m.$^3$, according to conditions, so that schemes which involve a cost in excess of these figures can only spell loss to the farmers. The amount of water required per acre for various crops is given as 2000 m.$^3$ for cereals, 4000 m.$^3$ for citrus, and 12,000 m.$^3$ for bananas. Ghor (Jordan valley) lands on which vegetables are grown with other crops can usually be profitably farmed where the depth to water lies between 10 and 20 m.

Although various suggestions are made in the report for ameliorating agricultural disabilities in Transjordan, little encouragement is given to improve matters by engineering projects. To the inhabitants themselves, it is asserted, must be left the execution of works likely to conserve and utilize to its full the scanty rainfall that falls on the country. Such a conclusion few acquainted with countries where the conditions are neither worse nor better would care to dispute. The author demonstrates by figures that schemes designed to impound water in reservoirs, to carry water long distances in canals, or to develop ground waters, are mostly uneconomic, but he is satisfied that much can be done to conserve water now unused by impeding run-off, insulating canal beds, and arranging the orderly distribution of spring and river waters. Arrest of surface run-off by afforestation and terracing, scientific tilling, and prevention of soil erosion, would all effect an improvement in course of time; but Transjordan suffers from the same troubles as so many other arid countries where rainfall is too inadequate and capricious to support organized agriculture on a large scale. The country has always sustained a restricted pastoral population content to live a frugal existence and accept the punishments inflicted by nature on improvidence. Brief periods of prosperity occasioned by rains above the average have often led either to attacks by envious or avaricious neighbours, or to an increase of herds which soon results in overgrazing and decimation of animals by disease or starvation. Those who like the writer have witnessed the hostility of peoples to any interference with past customs which involve a sacrifice on someone's part can but feel despondent. Active and passive resistance to afforestation in Cyprus, where its influence would be of such enormous benefit to the majority, have broken the spirit of more than one official, and in Southern Europe troops have to be stationed around planted hillsides to prevent the depredations of goats or peasants in search of firewood. Equally jealous of their rights are those who by force, stealth, or purchase, have acquired rights over the effluent of springs or the transient or perennial flow of rivers. Security of tenure, enforcement of equitable terms, and protection from theft and violence are other essentials to encourage permanent settlement and land improvement.

Divergent views are still held concerning the cause and age of deserts in many countries, but in the case of this part of the world biblical history gives us a picture dating back some thousands of years. Proof of more or less stationary climatic conditions lies in the knowledge that Palestine is on the northern edge of the limit where the date-palm bears fruit, for the fruit is never mentioned in the Bible, whereas vines and grapes get constant reference, indicative alike of warmth and absence of severe cold.

It would therefore appear that Transjordan could never support unaided a population far in excess of the present. No mineral resources of conspicuous importance have been discovered. Ores of iron, copper, manganese are known to occur, and in the non-metallic class phosphates and gypsum are plentiful. The most intriguing possibility is petroleum; indications are pronounced in

several localities, and have been investigated by experts. Without doubt test drilling will be undertaken on a return to peace.

The absence of an index is to be deplored, although the clear titles to the chapters and appendices gives a fair clue to the whereabouts of information sought. Many of the twenty-four folded well sections and graphs seem needlessly large to show the information they depict, and their presentation in groups on a smaller scale would have much reduced the bulk and weight of the volume. The maps are consistently good, and those showing the catchments of basins, geology, and the distribution of rainfall and farmed areas, are both informative and clear.

The death of G. S. Blake, who contributes so much to this volume, is much to be regretted, as his geological studies in Palestine and Transjordan had received widespread recognition. He was killed whilst engaged in prospecting for minerals in the Dead Sea area, when his party was attacked by armed bandits.

A. BEEBY THOMPSON

## SURVEY IN WAR

SURVEY IN WAR. Third edition. (Chapter VIII of Survey of India handbook of topography.) *Dehra Dun*, 1939. 10×6 *inches;* 167 *pages; diagrams.* 1*s* 6*d*

THIS handbook contains such valuable information, concisely written and occupying a very small space, that all military survey officers should certainly carry their own copy with them for constant reference. There is much to learn from it that does not appear in the usual text-books and military manuals. The pamphlet is not designed for the learner but more for the after guidance of survey officers. Survey officers are not the only ones who can benefit by a study of it. In an army expanded to the present enormous dimensions there must be staff officers at various headquarters who really do not appreciate the value of surveys in so far as they affect the success of an army in the field. This handbook should help greatly to improve their understanding of the subject. Close and timely cooperation between the survey service and the General Staff is emphasized, and staff officers should certainly study Section II of the handbook, particularly paragraph 46.

Section I deals with the duties and organization of the survey service, which is controlled by the General Staff in the same way as that of British Survey Services, as laid down in Field Service Regulations. There is considerable flexibility in the employment of a survey company as the Company Commander can use his sections to suit demands (para. 7). A Field Survey Company has on its establishment one officer who performs the duties of adjutant and quartermaster. It is his responsibility for the proper maintenance of professional records, stores, personnel, and interior economy. This system enables the Company Commander to devote most of his time to technical matters and the direction of survey operations. The Field Survey Company is composed of a company headquarters, one reproduction section, three field survey sections, and one air-survey section. The war establishment of a field survey company authorizes twenty-four signallers. This allows for six visual terminals to be manned. All survey officers no doubt realize the value of having signallers out in the field.

Section III deals with triangulation, which is the usual straightforward triangulation familiar to all survey officers. The rendition and distribution of trig. data to those concerned is organized on thorough and efficient lines (para. 95). A letter notation is used for grading the accuracy of points, which is simple and must prove valuable to those concerned (para. 98). A great point is made of close liaison between O.C. Field Survey Companies and the R.A. survey. Paragraphs 99–106 show very clearly the essential points of relationship between the Field Survey Companies and R.A. survey services. It is the responsibility of the O.C. Field Survey Company to provide the coordinates of the centres of vertical air photos. R.A. are then able to scale the coordinates of targets from these central points by the radial line method (para. 104).

Section IV describes air photographs. Photographs are provided by the R.A.F. on demands submitted from the survey service through the proper channels. Importance is attached to stereo-obliques and the method is used extensively for selecting points for theodolite observations (para. 119).

Section V describes air survey. A useful method that is recognized, but accepted as being laborious, is the compilation of air photos from late data and their subsequent gridding (para. 132). The grid of course would in most cases be distorted, but that should not affect greatly the accuracy of the coordinates of points scaled from it. Bearings and distances should of course be computed from these scaled coordinates and not scaled from the compilation. This omission from the text is serious, as the point may not be so obvious to a not very experienced officer. It might have been useful to have also added an explanation that a compilation from late data having a distorted grid can be rectified simply and reasonably quickly by redrawing square by square in a correct standard grid, slipping the tracing over each square in turn. In the reviewer's opinion the method of gridding a compilation from late data is not as laborious as it might be if the grid-line cutting points are determined by slide rule instead of normal calculation. Furthermore, the method described in the handbook of determining the "mean scale" and drawing in the arcs to the nearest grid-line is not very good. Scale factors along a line joining two adjacent points can be very quickly determined on the slide rule and the corrected lengths of the arcs worked out for that immediate vicinity in accordance with those factors.

There is a slight difference in the notation used in the formula for height determination from air photos (para. 140). The symbol p is used for the principal point base of an overlap. The symbol used by the Air Survey Committee, which is familiar to survey officers of the British Army, for the length of the air base is B. Para. 145 describes the black-and-white method of separating outline and hills for reproduction by photography and helio. To very many this method is a novel one and should save much time in reproducing the original air survey map.

Ground surveys, mapping, and published maps, are described in sections VI and VII. These two short sections do not provide anything new, but they give good tips and set out clear methods of organization. It is very pleasing to see that two range-finders are provided for the H.Q. of each field survey company. It is seldom that the range-finder is recognized as a surveying instrument, but when used intelligently it is an invaluable part of the topographer's equipment. A coordinatograph forms part of the standard equipment of the air survey sections. Those who have had experience of this instrument will recognize the value of it. Officers commanding Field Survey Companies will appreciate the clear instructions that can be passed on, as they stand, to subordinate officers and section N.C.Os.

Section VIII, covering thirty-one pages of text, describes reproduction in the field and is very clear and comprehensive. Processes for producing sun prints and ammonia dry development prints as well as other types are explained. Even very skilled lithographic printing officers can at times have had no experience of these simple methods and the methods and formulae given should be useful to them.

There are sixteen appendices: all give useful and valuable information. Appendices X and XI give photographic formulae and describe the Vandyke process, respectively. Appendix XV describes instruments in war equipment not in normal peace use. The ¼-plate roll-film camera used in conjunction with a box sextant and Abney level is a useful outfit to have if limited time is available to survey a difficult or inaccessible piece of country as the photographs can be plotted subsequently (para. 1). Paragraph 5 of Appendix XV gives a number of methods and their formulae that can be solved rapidly with a slide rule. Although slide rules form part of usual survey equipment it is seldom that handbooks are provided that will explain the solution of some survey problems. From this point of view this appendix should prove to be useful. Appendix XVI describes the adjustment of field service portable process cameras and enlargers. Those in possession of cameras as part of their war establishment equipment complete with the authorized trained personnel, as well as those who improvise their own photographic equipment, will find guidance and help in this appendix.

There is a good index at the back of the handbook. A small point, but one that can irritate the reader at times, is the free use that is made in Section VIII of Hindustani words. Even though the handbook is produced for the use of survey units in India others have not the knowledge of that language. Most of us recognize the word *khalāsis*, but such words as *chonga* leave us in wonder. There are not sufficient words of this kind used to warrant a special glossary of terms, but their English meaning might have been given in parenthesis.

In conclusion, the reviewer would like to offer his congratulations to the Survey of India for their production of this handbook, and hopes that a large number was printed for publication. It would be a pity if this handbook, at the low cost of 1*s* 6*d*, were unobtainable because of it having gone out of print.

W. E. BROWNE

# REVIEWS

## EUROPE

THE EASTERN MARCHLANDS OF EUROPE. By H. G. WANKLYN. *London: George Philip*, 1941. 8½ × 5½ *inches;* xxiv + 356 *pages; sketch-maps.* 12*s* 6*d*

Miss Wanklyn deals with eight countries of Eastern Europe which owed political independence to the Treaties closing the last war. Placed in four groups they comprise the Baltic countries, Poland, the Danube lands, and Yugoslavia. Her aim has been to summarize their historical traditions, the interrelations of each group, and their religious, cultural, and economic development, concluding with an examination of their claims to independent existence. Throughout geographical influences, though not treated separately, are given due weight. The author describes the book as the outcome of journeying and reading during the last ten years, within the reach of many people in Great Britain. Few of those however to whom this opportunity offered could give so lucid a summary, or

maintain so judicious a balance among the welter of historical, political, and economic problems.

The area, extending meridionally through continental Europe from the Arctic Ocean to the Adriatic, is not a geographical unit: the historical unity it presents, tragically exemplified in its present condition, has emerged from the interaction of conflicting influences, stronger at various periods, more profound in certain areas. Miss Wanklyn makes clear how these antecedents, the general westward movement of Slavs and Finno-Ugrians, the contrary Germanic expansion, the influence of Byzantium and the Roman Church, the maritime and industrial development of Western Europe, and the imperial rivalries of the nineteenth century, conditioned the settlement reached after the last war, and eventually brought about its break-up. The relative importance of these influences, and to some extent the necessity of compression, has dictated the point of view adopted in treating the individual countries. The section on Czechoslovakia, one of the most interesting, is largely historical; Poland does not receive the detailed treatment accorded to others; geographical influences supply the interest of the chapter on Finland; and the treatment of Estonia is economic. This variety however has not resulted in destroying the unity of the theme.

Arising from the position of these marchlands, certain adjacent areas closely related to them fall outside the scope of this survey; the Danube basin and the Balkans, for example, are not dealt with in their entirety, though the nature of their common problems is indicated. Miss Wanklyn rightly insists that in seeking an acceptable solution for the economic problems of the Danube basin it is not enough to propose economic unity if that implies a permanent segregation into industrial and agricultural states. This division, as she shows, may be founded only upon the stage of economic development attained, not upon inherent resources, natural or human. This is but part of the wider problem of the future relationship of industry and agriculture in Europe, which is further complicated by the interests of the overseas producer. In the past the development of western Europe has had adverse effects upon the eastern borderlands. It is a commonplace that maritime and commercial expansion left Venice to languish in the backwater of the Adriatic; Miss Wanklyn shows that not Venice alone, but Kraków, Łwow, Beograd, and other cities suffered through this development which affected the stability of the south-eastern states, not only at a stage which held considerable promise for their future, but at the moment when the Turkish threat was imminent. This region will indeed provide "testing grounds of European security" in the future, and ultimate success, while benefiting western Europe directly, will repay its no small debt to the east. How much weight should be attached to cultural, economic, and traditional considerations will require careful examination; the author makes some rather tentative and not very conclusive suggestions, but the real value of her work lies not here, but in providing the material for the understanding of the permanent background.

The text is supplemented by over eighty sketch-maps and many bibliographical references. The maps, occasionally rather small and cramped, have kept pace remarkably well with the course of events, and must represent much labour. Place-names in a work of this kind are often a cause of difficulty. Alternative forms are given in most cases, though there are some inconsistencies. The official name of Yugoslavia had not since 1929 been "The Kingdom of the Serbs, Croats, and Slovenes," and the remark that "there is only the one proper name, Hungary, . . . for the unit created by the Treaty of Trianon" reads curiously.

G. R. C.

## ASIA

OLD ROUTES OF WESTERN IRAN: narrative of an archaeological journey. By Sir AUREL STEIN. . . . Antiquities examined, described, and illustrated with the assistance of FRED. H. ANDREWS. *London: Macmillan*, 1940. $9\frac{1}{2} \times 6\frac{1}{2}$ *inches;* xxviii+432 *pages; illustrations, diagrams, plates, and folding map.* 42*s*

A new record of a new journey of "archaeological reconnaissance" by the veteran explorer Sir Aurel Stein is an event of the first importance alike in the geographical and the archaeological world.

This book deals with the last and longest of its author's four journeys during 1932–36 through southern and western Persia, undertaken to discover what remains of antiquity can still be found along the ancient routes of this region. Much of the terrain was unmapped and unsurveyed. The impressive and picturesque ruins of a series of great bridges bear testimony to the volume of trade and traffic which from Sasanian to early Islamic times, and probably long before, passed up and down from the fertile plains of Susiana to the high plateaux of central Persia.

In the Bakhtiari hills, so long almost inaccessible to European travellers, Sir Aurel discovered the ruins of an ancient Parthian shrine whose bronze sculptures and other antiques strikingly reveal the influences of Greek art and culture that followed Alexander's conquests. In the uplands of Luristan, that have for centuries served merely as grazing grounds for the flocks and herds of semi-nomads, he found abundant evidence that a permanently settled population of a considerable degree of civilization had flourished there some two thousand years before the Christian era. Another discovery of great interest was a mass of corroborative evidence of the date of the burials from which the so-called "Luristan bronzes" have so unscientifically and ruthlessly been plundered by mercenary fortune hunters.

Sir Aurel's pre-occupation with archaeological discovery by no means blunted his interest in and sympathy for the present-day inhabitants of the regions which he explored. He has much of value to report about the peace and order that prevail in the once bandit-ridden tracts which have now come under the effective control of Shah Riza Pehlevi. But he also tells of the very real hardship of those nomadic tribes, accustomed to winter in the lowlands and to take to higher ground only when melting snows set the pastures free for their flocks, who have been compelled, with however benevolent and far-sighted intention, to settle down to agricultural life and build permanent houses in climatic conditions which they find severe.

It would be an impertinence to offer to so famous and experienced a traveller a fresh tribute of admiration on his comprehensive learning or amazing physical endurance. This book ends with grateful acknowledgements of the help from various sources that has made its publication possible and has not allowed war-time stringency to spare expense in the reproduction of fine maps, photographs, and plates. E. O. L.

## POLAR REGIONS

POLAR EXPLORATION. By ANDREW CROFT. Epics of the twentieth century. $8\frac{1}{2} \times 5\frac{1}{2}$ *inches;* x+268 *pages; illustrations and maps.* 7*s* 6*d*

For long we have waited the writing of a good account of modern exploration in the Arctic and Antarctic. It is well that this has been left to the present time which marks a halt to the long period of travel and research in these regions. There are many difficulties in writing a history of modern exploration. The great amount of work which has been done, the large number of expeditions

from different countries which have gone out, the languages in which their results are published and, of late years, the highly technical scientific research which has been undertaken, all combine to make the historian's work an exacting task. The author however is a man not easily put off by difficulties. He is well qualified for the job and he reduces this formidable array of material to an understandable and most readable book.

A short historical introduction leads us to the position which polar exploration had reached at the beginning of the century, by which time the great secrets had been unveiled but many blanks remained to be filled in. The main part of the book starts with Peary's journey to the North Pole, and ends with Rymill's expedition to the Antarctic in 1934–37. Few will quarrel with the author over his choice of the expeditions he has described. All those which have carried out good work in this period are included, though the accounts of some of them have to be brief. In every case he shows us the aims of the leader, his way of carrying out his plans, and the difficulties which had to be overcome. As well as this he gives us a very good idea of what each expedition was like, and finds space to tell of any adventures and incidents which happened by the way.

To begin with the book is most useful in showing the part which was played by the great men of exploration in past times. Those who, like many of us, are hazy about Bylot, Baffin, Button, or Belcher, and what they did, will find their achievements here set forth. In describing the great sledge journeys, whether in the north or south, the author is at his best. Here he is an expert, having himself taken part in many such journeys, one of them the longest and most notable of our time. With eager pen he tells of the aims which inspired their plans, the difficulties which beset their ways, and the achievements which rewarded their completion. In reading of these long marches across the snows we feel as the leader. We sense his heart thrown forward to the unseen end, his mind casting up the eternal arithmetic of speed and rations, his fears and hopes of weather and surface, and his cares for the strength of dogs and men.

Here is no armchair criticism of leaders and their methods, no invidious comparisons between expeditions, although the author is in every way well qualified to make them. The great journeys of Amundsen and Scott to the South Pole are particularly good examples of historical description, and here as elsewhere the work of each expedition is set forth with due credit given for success and careful, sympathetic explanation where it was not attained.

Yet it is the efforts of the past generation which we think will always have the greatest hold on the imagination. Not all the lengthening tally of successful expeditions will eclipse their epic journeys and their gallant failures. They knew no lure of riches nor did they even expect to make great scientific discoveries. The bogeys of scurvy and frostbite which to us are remote possibilities were to them their daily companions of the march. On they went, do or die, sometimes both. They knew it was worth it.

If one may draw a conclusion from the book, it is the same as General Wavell has drawn from military campaigns: success depends on organization. Organization of dogs and food and equipment rather than brilliant or cunning decisions in the field.

Few could have got so much into so thin a book and at the same time made it one which is not only a pleasure but an excitement to read. None could have brought to the subject a better knowledge of Polar craft or closer acquaintance with all the chief expeditions of recent years. Another edition might contain a couple of better maps, perhaps folded into a pocket at the end. Otherwise there is no improvement which the reviewer can suggest. A. C.

# THE MONTHLY RECORD

## GLACIATION OF THE CENTRAL APENNINES

A valuable memoir in German, handsomely illustrated, by Karl Suter, with the title "Die eiszeitliche Vergletscherung des Zentralapennins," forms Beiblatt 31 [vol. 74 (1939)] of the *Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich*, and an abridged version of the author's research in French "La glaciation quaternaire de l'Appenin central" appears in the *Revue de Geographie alpine* (vol. 28, 1940, No. 4). In all parts of the Apennines the majority of the Pleistocene glaciers developed on the shaded northerly slopes (ubac). On these the floors of the cirques are at a nearly constant level between 1800 and 1900 metres, but on the sunny slopes (adret) between 2200 and 2400 metres. The author maintains that the mean altitude of the cirque floors corresponds with that of the Pleistocene snow-line. Partly from this relation and partly from Kurowski's contention that the mean altitude of the surface of a glacier corresponds very nearly with the snow-line, Suter infers that the limit of perpetual snow during the Quaternary Ice Age was between 1750 and 1800 metres on northern, eastern, and western slopes in the Central Apennines, and between 2200 and 2300 metres on the southern sides of the mountains. The general snow-line however lay 1000 metres lower in the northern Apennines than in the southern, a difference attributed to heavier precipitation and not to lower temperature.

It is stated that in a cirque facing north-east between 2874 and 2985 metres on Monte Corno (Gran Sasso d'Italia), the extreme summit of the Apennines, there exists to-day a small glacier known as the Ghiacciaio del Calderone. It is described as much smaller than the largest glacier in the Pyrenees on Maladetta, though larger than the Veleta firn field of the Sierra Nevada in southern Spain. Unfortunately the author's reference to the highly interesting question of present-day ice conditions is obscure and meagre, and he is probably wrong in regarding the Calderone glacier (if it be really a true glacier) as a relic of a "recent" colder epoch when the Apennines were perennially snow clad at a level about 1200 metres higher than in the Quaternary glacial period. It should be noted that the winter snowfall in the Abruzzi mountains at the present time is very heavy through a long season, and that the mean July temperature near the summit of Monte Corno (9600 feet) must be about 44° F. as deduced from the sea-level temperature of that month in Central Italy. Now this temperature at the warmest time of year may be low enough to permit the formation of an incipient or actual glacier in a situation specially favourable to the accumulation of large quantities of drifting or avalanching snow on a mountain which does not quite reach the true climatic snow-line. In Scotland it is certainly not now contended that the permanent or semi-permanent snow-beds lying in the cold gloomy corries of Ben Nevis and Cairngorm require any other explanation than the low summer temperature which at 4000 feet barely exceeds 40°.

## THE RUGGED FLANKS OF CAUCASUS

In our review of Mr. Baddeley's book, 'The rugged flanks of Caucasus,' we promised a separate note on the method by which the author had drawn the admirable plates from photographs. This point Mr. Heawood had inquired of the Printer to the University of Oxford, who replied that he had never himself seen his friend John Baddeley at work on the drawings, but that his chief executive officer describes the process thus: "Mr. Baddeley used first of all to obtain a photographic print (enlarged from his original and smaller print) and

then to trace the main features on to tracing paper. Having done this he placed the pencilled tracing over a sheet of his own favourite roughish-surfaced hand-made paper and by working over the tracing with a sharp 4H pencil he transferred an impression of the main features on to the handmade. Then he used to make his finished drawing, with the photograph beside him, using a 4B pencil, finishing off his drawing by spreading his pencil lines to produce shaded effects by the use of a soft French rubber which he used to buy from a shop in Jermyn Street."

It is thus explained how Mr. Baddeley obtained something of the effect of a lithograph on roughly grained stone, yet evidently based upon a photograph. The plates were then photo-engraved by Messrs. Emery Walker. This was the technique "peculiarly his own," briefly mentioned by the late Sir Charles Hagburg Wright in his Memoir of the author.

## AN EARLY MAP OF THE SOUTH SHETLANDS

We are further indebted to Lieut.-Commander Rupert Gould for reference to a brief note by Captain Richard Sherratt of 'Observations on South Shetland,' published with a sketch-map in the *Imperial Magazine* for December 1821.

Captain Sherratt had commanded a vessel unnamed, which sailed to the South Shetlands in the autumn of 1820, but had been wrecked. His sketch-map is very conventional in outline, but interesting as showing what is certainly Elephant Island under the name of Seal Island, and an outline beyond with the legend "Land supposed to be about here": presumably Clarence Island. MacFarlane Strait is named Yankee Straits, and English Strait bears the name of Perry. Esther Harbour and Clothier Harbour are named the two best harbours on the north side, but Potter's Cove the best harbour in the whole group at present known. Clothier Harbour he shows behind Table Island on the north-west coast of what must be Greenwich Island, whereas Powell, who returned there after his voyage to the South Orkneys, shows it on the north of the next island to the east, Roberts Island. The outlines of King George's Island differ so much between Sherratt and Powell that it is difficult to compare the latter's position of Esther Harbour with Powell's Ester's Harbour, but Sherratt's placing of Potter's Cove, somewhat disguised by his omission of Field's Strait, agrees fairly with Powell. A line of four islands, Brains Isles, south of the Shetlands Group in Bransfield Strait, must have been icebergs. Captain Sherratt's sketch has the appearance of being too rough to be of any importance for the outline, but his account of the harbours in the eastern islands has some interest for the early history of the British sealing in these waters. The map belongs to the season of 1820–21, and seems to be the earliest published British map of the archipelago. A photostat from the volume of the *Imperial Magazine* in the Cambridge University Library may be seen in the Map Room of the Society.

The Editor of the *Imperial Magazine* claims that his journal had been in possession of all the leading facts about the South Shetlands before their existence was announced to the public, but at the desire of their correspondent "who was in the first vessel that ever touched on these inhospitable shores," they had omitted giving them publicity until several weeks had elapsed, which enabled the editor of a weekly journal (no doubt the *Literary Gazette* of November 3, 10, and 24) to announce the existence of these distant lands just before the day of publication of the *Imperial Magazine* had arrived; but the *Literary Gazette* was writing of Bransfield and Smith in January 1820; Sherratt's voyage described in the *Imperial Magazine* was a year later, and there is no reason, other than the obscure reference to a "correspondent," to think that Sherratt ever sailed with Smith on the *Williams*.

## THE LOCATION OF INDUSTRY

A discussion on the Report of the Royal Commission on the distribution of the industrial population, opened by Professor J. H. Jones, is published in the *Journal* of the Royal Statistical Society, vol. 103, pt. 3, 1940. He considered that industries may be placed in three groups: those supplying products or services which could only be provided on the spot; those which had arisen in certain areas through a combination of natural factors and external economies of a specialized or technical character; and those which flourish in places chosen for no obvious technical reason, favoured by general external economies. The last group alone could be re-located, probably with little or no economic loss. Generalizing broadly, the expanding regions in the last century were due to the growth of a basic industry; the rate of growth, measured by output, was in time reduced to the rate of growth of the population of the country; improvements in technique then reduced the quantity of labour required, so that ultimately additional basic industries, attracted by natural conditions and special economic considerations, were required to support the growing population. The growth of the London region after 1918 however had other causes. It was mainly due to industries in the third group. Their relative increase was not much more rapid than that of these expanding industries in other parts of the country, and was associated with extreme depression in the basic industries. To have prevented the post-war movement of population, the areas outside the London region would have had to offer far greater relative attractions than could be expected from industries of the third group. This movement towards London demanded immediate attention; a reasonable balance of industrial development should be aimed at throughout the country, and a national authority was required to deal with these problems. Close investigation would be necessary to decide whether the changes recommended by the Commission would impose economic loss on the country. An industrial transfer, though beneficial to a firm, might prove uneconomic to the community as a whole. With the growth of cities, the relative costs of production on old sites tend to rise, but the heavy expense of moving often delays the change. Statistics of national income give little help in estimating the true value of large-scale industrial development in a given area.

As was emphasized by subsequent speakers, the expansion of south-east England was the outcome of the depression of the basic industries, and the increasing part played by consumer's goods in the national economy. Manufacturers of the latter, especially where the quantity of raw material used is relatively low, will establish themselves close to their market. London, as the seat of government, with many social amenities, and a large entrepôt trade, was naturally attractive to light industry. Sir Montague Barlow thought that the latter could be controlled without serious loss; unless checked this southward movement would continue, with serious effects upon national welfare. Sir Gwilym Gibbon considered that inquiry into the probability of economic loss should have preceded the recommendations of the Commission, and challenged the competence of a board to control industrial development. London's real need was for planning, in the centre as well as the outer ring. Mr. Glenday thought that the crux of the problem, which was outside the purview of the Commission, was the industrial future of the country, and particularly what industries could restore the depressed areas.

The discussion thus centred largely upon the concentration of industry in the south-east, and the broad economic trends responsible for this. It suggests the question how far any central controlling body can be expected in the future to foresee such trends, and, even if foreseeing them, to check movements of population, considered detrimental to the community, but occasioned by developments

in world economy. Perhaps the most that could be expected of such a body would be the planning of the new concentrations of population with regard to amenities and the preservation of areas of special value, *e.g.* rich agricultural land, taking into account the factors set out in the Society's discussion of the problem published in the *Journal* for July 1938.

## AN IMPORTANT GIFT TO THE SOCIETY'S LIBRARY

During his life Mr. Henry Yates Thompson gave many valuable books to the Society's Library, and after his death in 1931 Mrs. Yates Thompson made in memory of her late husband the generous gift of some of the choicest early atlases contained in his collection. Mrs. Yates Thompson died in January 1941 and the Trustees of her will, in accordance with her expressed wish have presented to the Society a splendid Portolano by Baptista Agnese and a number of fine and rare books not hitherto in the Library.

Two of the volumes are of importance for the history of British cartography. One is the collection of forty-four small county maps, engraved by P. Kaerius and issued in 1599, which with their titles translated into English were re-issued in London in 1620. The maps are preceded by a manuscript account of the order of the first Parliament in the time of Edward the Confessor; each map is framed in a MS. border with the armorial bearings of the county families, and is followed by two or three pages of manuscript. The general map of Yorkshire is in manuscript. The other volume contains a set of early proofs of Speed's county maps, later published in 'The theatre of the Empire of Great Britaine,' 1611. Another important volume has nine of the eleven charts engraved by A. Ryther to accompany Ubaldini's 'Discourse concerninge the Spanishe fleete,' 1590.

The gift also includes two plans of Paris; the earlier by Louis Bretez, engraved by Claude Lucas, Paris, 1734–39, in twenty large sheets bound in red morocco with the arms of the City of Paris on the sides; the later by Pasquier and Denis, in two editions, 1758 and 1765. Another fine volume is the second edition of Rocque's Survey of London and Westminster, 1751, with some sheets corrected to 1766. Other items are Robert's 'Atlas portatif,' Paris, 1748, with the arms of Madame de Pompadour on the binding; four sections from a large eighteenth-century map of France carefully folded and bound in a pocket volume; and a copy of the 'Circuli sphaerae' from Honter's 'Rudimentorum cosmographicorum libri III,' Zurich, 1548, with the maps attractively coloured.

This splendid gift will in due course be displayed in the case which Mrs. Yates Thompson presented to the Library in 1935 to display a selection of the rarer gifts which had come to our Society from Mr. Henry Yates Thompson's Library.

## EVAPORATION IN SOUTH AFRICA

Evaporation losses are a matter of considerable importance to hydraulic engineers in designing irrigation and other storage plants, therefore in order that his figures may be used at once Mr. Levinkind has published the results of a preliminary investigation on "Gross evaporation from standard tanks," in the *South African Journal of Science* for April 1940. At present there are only forty-one recording stations in the Union, but it is hoped that there will soon be more. The equipment of each station consists of a galvanized iron Symon's evaporation tank, 6 feet square by 2 feet deep, sunk into the ground to within 3 inches of the rim, from which readings can be taken correct to 0·01 inch; and a rain gauge with its rim set approximately level with that of the tank. The tanks are placed to receive maximum exposure to wind and sun, and are fenced with wire

netting; if there is a trained worker at the station, other meteorological records are kept.

The author talks of "gross" and "net" evaporation; the former is the actual tank reading, the latter is the tank reading corrected for precipitation. The use of the terms gross and net is misleading: the gross evaporation is not an evaporation figure at all, but the difference between evaporation and precipitation; in dry climates, such as parts of South Africa, this figure would bear some relation to the evaporation; in damper climates the effects of evaporation would be entirely obscured by the rainfall. The so-called net evaporation is the true evaporation of the experimental tank. Moreover it is not always clear when annual evaporation is referred to whether the gross or net annual evaporation is meant. If the annual net evaporation of a large sheet of water is required the tank results must be corrected by the "reservoir equivalent" to allow for the lag in temperature changes between a large water area and a small tank. In South Africa the annual "reservoir equivalent" is 0·88, a reduction of 12 per cent. on the net annual evaporation figures; for the hottest months the reduction is as high as 30 per cent., in the cooler an addition of 10 per cent. must be made.

From tank readings, a rather speculative map, the first of its kind, has been drawn to show the distribution of mean annual gross evaporation over the Union of South Africa. It is unfortunate that the gross figures were used for this as corrections have to be applied to give the actual evaporation. The values on the map range from 50 to 60 inches along the coast to 100 to 110 along the Orange River in the north-west; but it is emphasized that the indications are only tentative and subject to correction when there are more stations. Though the records cover only a few years the writer is probably correct in saying that evaporation is much more constant from year to year than temperature, rainfall, and most other meterological elements. The records show that a careful study of meteorological and other controlling conditions must be made before evaporation data collected in one locality can be applied to another even if comparatively near. Thus two stations near Kimberley differing in altitude by about 400 feet and only 18 miles apart were found to differ notably in evaporation.

## OBITUARY

### SIR EDWARD DENISON ROSS, C.I.E.

When Sir Denison Ross died, in the autumn of last year, he was within a few months of reaching his seventieth birthday. Few men, surely, have packed so much into an equal space of time. He had travelled extensively in three continents. He had been head of an important Muslim school at Calcutta, and later had been placed in charge of the Imperial Record Office there and had organized the Victoria Memorial Hall established by Lord Curzon. Returning to England, he had served for a time in the British Museum, and had then been appointed to the important post of Director of the new School of Oriental Studies, becoming at the same time Professor of Persian in the University of London. He had had his share of academic honours; had been decorated and knighted. A prominent member of several learned bodies, he had acted as Director of the Royal Asiatic Society and President of the China Society. In our own body he had served as a member of the council and as chairman of the Permanent Committee on Geographical Names, in succession to Lord Edward Gleichen.

His chief monument is the School of Oriental Studies, the establishment of which redeemed this country from the reproach that, although its material interests in the East were so great, it had no such centre of oriental learning as might be found in Paris or Berlin. On the development of this institution Ross lavished his care for twenty years; and if any one doubts the value of his labours, let him read the tribute paid to them by Professor Gibb in a recent number of the *Journal of the Royal Asiatic Society*. A second important service rendered by Ross to his country was the part he played in reviving the ancient friendship between ourselves and the Turks. He was closely in touch with the Ataturk, and was frequently consulted by him on the subject of his reforms, particularly those relating to the language. The contacts thus established did much to promote the *entente* that now happily prevails; and the value of Ross's services in this direction was recognized by the Foreign Office by its appointment of him, at the close of 1939, to the post of head of the information bureau at Istanbul. And in that city, appropriately enough, for he ever loved the language and culture of the Turks, he sleeps his last sleep.

Ross left behind him a host of friends, both at home and abroad. His genial manner, his lively conversation, and his sense of humour made him welcome in any company and enlivened the dullest. He radiated energy, and the zest with which he enjoyed life was infectious. Critics in academic circles may have hinted that he was a linguist rather than a scholar and that his knowledge was wide rather than profound; others that in his literary work he was apt to engage in fresh tasks without regard to existing commitments; or that he was too impulsive and unmethodical to be a really good administrator, though his kindness and charm made him popular with his staff and still more with his pupils. Generous in his appreciation of other men's work, he never stinted his praise or withheld any assistance he could give. Jealousy or self-seeking found no place in his character, and he was openhanded to a fault. I never heard him use a bitter phrase concerning anybody, and I never knew him do a mean or ill-natured action. He lived fully and fearlessly; and the harvest he garnered, if it contained a few tares, was a rich and bountiful one. W. F.

## MEETINGS: SESSION 1940–41

Twenty-first Meeting, 7 April 1941. Major-General M. N. MacLeod, Vice-President, in the Chair

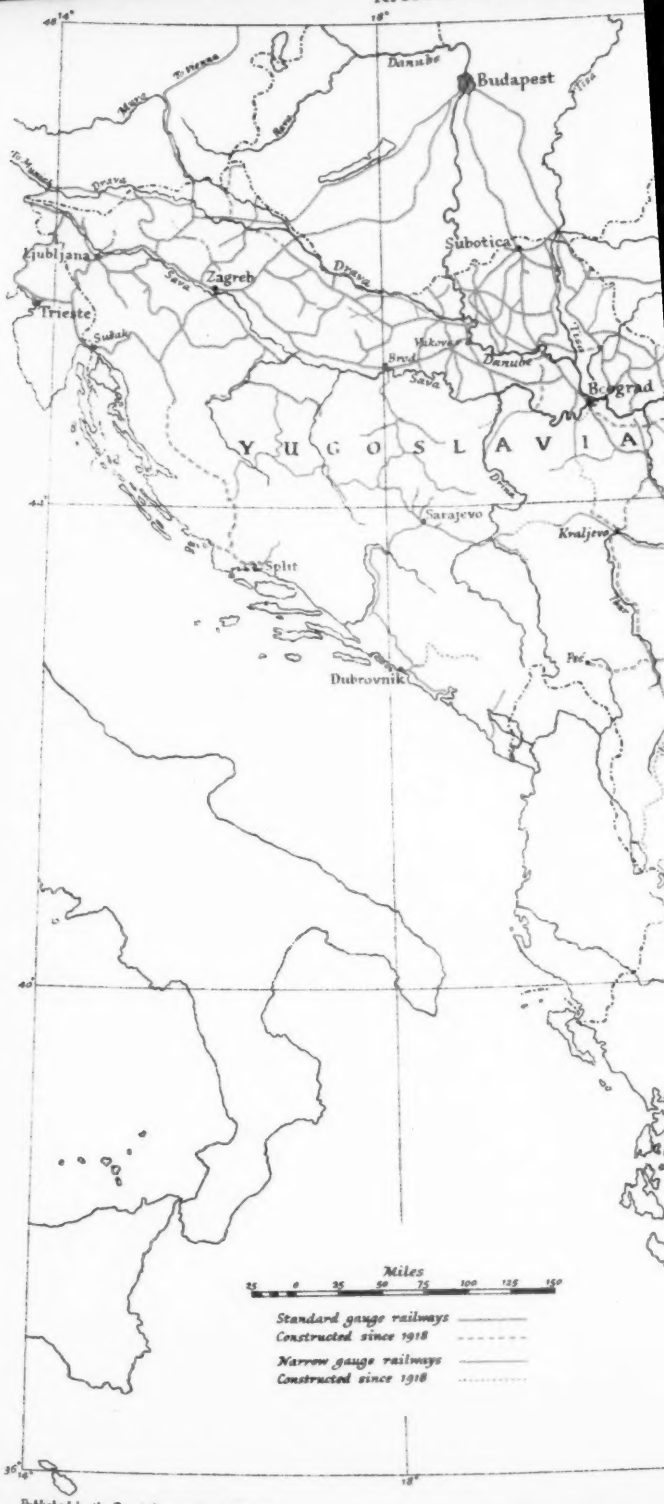
*Paper:* The Ouse flood problem. By Mr. W. E. Doran

Twenty-second Meeting, 21 April 1941. The President in the Chair

*Elections:* Dr. Isaac Ashforth; Mrs. Bradby; G. D. H. Cole; R. A. Derrick, A.M.I.Struct.E., F.R.S.A.; Mrs. C. F. W. R. Gullick, B.A.; Major J. T. Wilson (PH.D.).

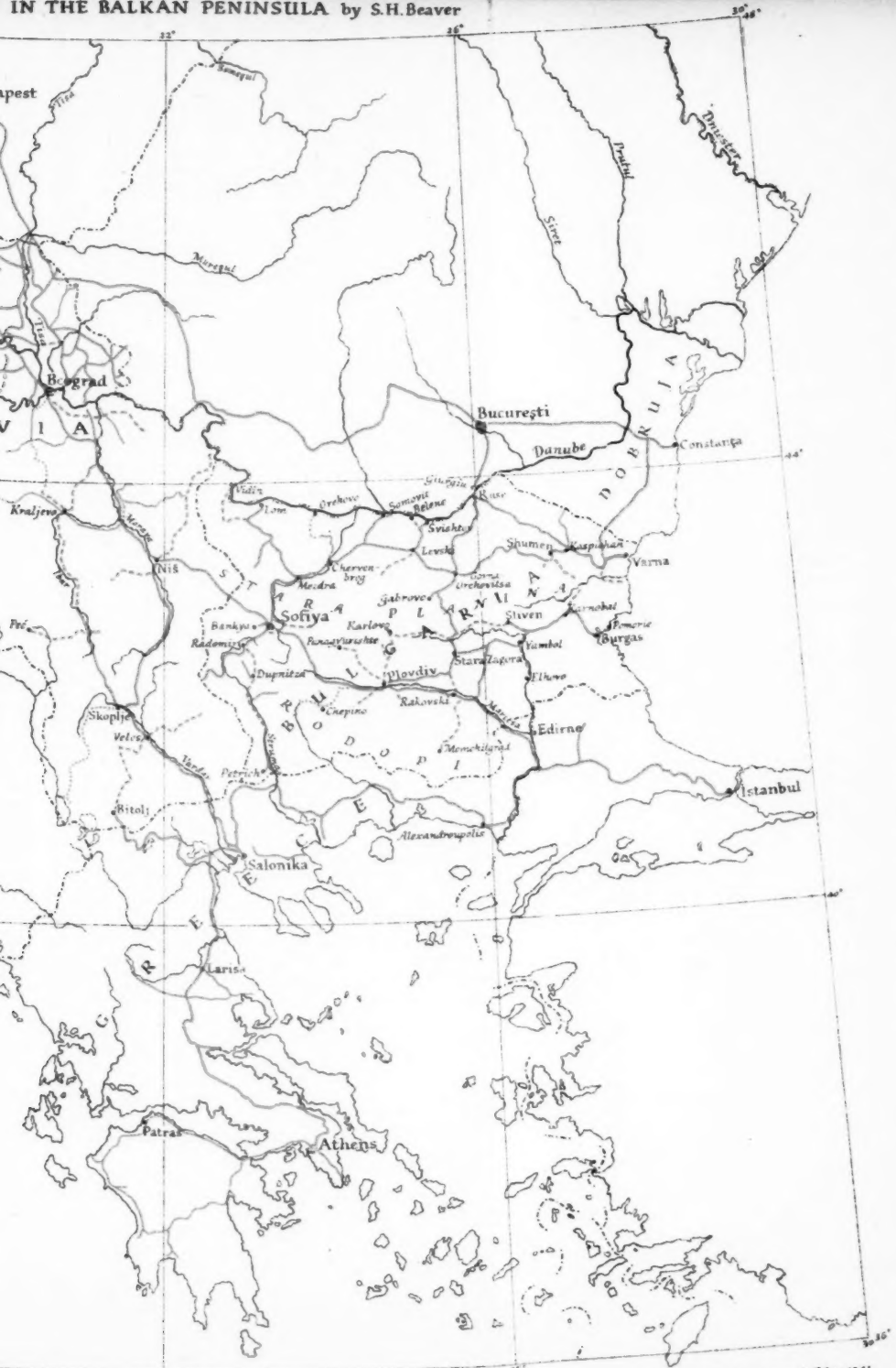
*Paper:* Berber Settlements in Algeria. By Lieut. G. H. T. Kimble, R.N.V.R.

Twenty-third Meeting, 28 April 1941. Geographical film: The voyage of the *Joseph Conrad* round the world. By Lieut. Alan Villiers, R.N.V.R.




Published by the Royal Geographical Society

IN THE BALKAN PENINSULA by S.H. Beaver




The Geographical Journal, May 1941